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FINAL REPORT

Study on radio interference regulatory models in the European Community

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STUDY ON RADIO INTERFERENCE REGULATORY MODELS IN THE EUROPEAN COMMUNITY

FINAL REPORT

This is the final report for the above study carried out for the Information Society and Media Directorate-General of the European Commission under contract *INFSO-B-2006/45682 (SMART n°2006/0011)* signed on 29 December 2006. The study was carried out between January and November 2007 by Eurostrategies sprl of Brussels and LS telcom AG of Lichtenau, Germany.

This final report was submitted to the European Commission on 26 October 2007 and finalised on 29 November 2007.

The opinions expressed in this study are those of the authors (Eurostrategies and LS telcom) and do not necessarily reflect the views of the European Commission.

Final Report

Study on radio interference regulatory models in the European Community

Contents

0. Executive Summary

0.1 Overview of Findings

Interference management is based on the concept that use of the radio spectrum is controlled through addressing radio interference instead of directly controlling its causes such as transmitters and antennas. This study has explored various facets of interference management and has sought to address the central question:

Can spectrum use be made more effective by spectrum management techniques which control interference instead of controlling transmitters?

It appears that there is no single answer to this question. Rather than having demonstrated that interference management techniques produce an all-round improvement in the efficiency or effectiveness of spectrum use, or a method for replacing standard techniques, it has instead been shown that the application of such techniques in some circumstances provide alternative and additional tools to the spectrum manager which may encourage more flexible (both in terms of technology and service) access to the radio spectrum.

Our argument in favour of interference management depends on a combination of the resulting lower technical constraints and spectrum trading concepts to maximise the value realised. However, we recognise that some groups of spectrum users (e.g. passive services, safety-of-life), cannot easily be subject to full market forces and that therefore a “status quo” safeguard on interference levels will come into play.

It is also worth noting that some of these services (such as radio-astronomy) already inhabit an environment in which, in order to perform their daily work, they must manage interference as a fundamental necessity to provide access to the spectrum they require.

Each section of this report addresses a different aspect of interference management. The detailed conclusions are presented in section 0.2. However the key issues arising from this study are summarised on the following page.

MAIN FINDINGS OF THE STUDY

- To achieve the full benefits of interference management, the definitions of "harmful interference" and some closely related terms can be usefully redrafted. Mechanisms to translate them into meaningful mandatory technical and operational parameters on a case-by-case basis are needed.

- The concepts of harmful and permissible interference may be extended to provide a way of defining spectrum rights for licence holders and offer a means of enabling liberalisation through trading.

- Regulating receivers (in addition to transmitters) through the specification of receiver characteristics is not, by itself, a solution to enhancing spectrum efficiency. However there are benefits in encouraging an interference management approach in which, to gain additional capacity and hence value from a given band, receivers need to be designed to 'work harder'. This in turn can deliver greater spectrum efficiency.

- The remit of compatibility studies should be modified to answer questions based on a flexible interference framework instead of providing 'go/no go' decisions on whether two systems can work together.

- Technology and service-neutral licensing (as would be supported by interference-based licensing techniques) offers significant benefit for end-users but not necessarily for spectrum owners and network providers.

- The scope and detailed implications of EU Decisions and Directives which consider harmful interference and electromagnetic disturbance are not widely understood. Making harmful interference a sub-set of electromagnetic disturbance introduces much needed clarity.

- Methods of managing risk, vulnerability and performance, often applied in other industries, may be used in considering the scope and application of compatibility studies to support a more flexible approach to decision making.

There are ways in which the radio spectrum could, in the future, be managed which remove many of the distinctions, categorisations and divisions which currently define spectrum management. However, determining which of these have merit is complex and uncertain when set against the existing, well-established landscape of spectrum usage. What this study has shown, based on several different analyses, is that there are alternative ways in which spectrum 'rights' based on the concepts of interference management, could be defined, exchanged and valued.

Such rights can be divided in several ways. At the edge of every division is a border, and managing the conflicts at these borders is one of the key elements in ensuring spectrum efficiency. What is therefore required to manage interference effectively is a flexible spectrum management framework where administrations and users have access to the radio spectrum in an appropriate fashion whilst ensuring both 'quality of spectrum' as required and terms of usage which are not unnecessarily onerous. We have identified various mechanisms which allow progress towards such an open framework and we have shown that there are both technical and socio-economic benefits accruing from a more liberalised approach to spectrum access.

0.2 Conclusions and Recommendations

The following is a replay of the recommendations made as part of this study. The numbering of each recommendation is based on the section within this report where they are made. Thus 'Recommendation 4.2' is the second recommendation arising from section 4 of this report.

Recommendation 3.1: The following revised definition of harmful interference should be adopted in all appropriate Community texts:

> **Harmful Interference** means interference which degrades or interrupts radiocommunication to an extent beyond that which would reasonably be expected when operating in accordance with the applicable Community or national regulations

Recommendation 3.2: The definition of harmful interference requirements and variations thereof in individual Commission Decisions should be harmonised and existing Decisions should be amended accordingly.

Recommendation 3.3: The use of "non-protected" in each relevant Commission Decision should be aligned on the following basis:

> **Non-protected basis** means that no claim may be made for protection from interference received from radiocommunications operating in the frequency bands subject to this Decision and in accordance with the applicable Community or national legislation.

Recommendation 3.4: The EMC Directive to be amended to recognise the specific concept of harmful interference in order to recognise the possibility of harmful interference from electrical and electronic equipment.

Recommendation 3.5: The European Commission should work with spectrum users to produce an agreed technical definition for 'permissible interference'. Our suggested starting point is a 0.42 dB rise in r.m.s. noise or a 10% increase in outage.

Recommendation 3.6: The Commission should ensure that in the revision of licences to allow for liberalisation, the concept of a negotiated accepted interference approach is one of the possible ways in which spectrum users' rights can be defined.

Recommendation 3.7: CEPT, the Commission and national regulatory authorities should consider means of obtaining benchmark interference statistics and a common approach for recording and reporting trends. Furthermore, such statistics should be publicly available for study and comparison with the situation outside Europe.

Recommendation 3.8: Annexes C and D to this report should be considered as a basis for a possible common European approach to promote public awareness in radio interference, to provide information on how to solve simple interference problems and to inform the public about the organisations responsible for these matters in Member States.

Recommendation 4.1: The Commission should consider performing an impact and risk assessment on regulatory and socio-economic factors subsequent to a technical compatibility analysis by CEPT.

Recommendation 4.2: Mandates to CEPT should be specific in respect of requirements relating to sharing scenarios and technical regulatory conditions.

Recommendation 4.3: CEPT should be invited to propose a pragmatic working arrangement which would hasten the delivery of mandated reports to the Commission.

Recommendation 4.4: Public reviews on a Europe-wide basis are conducted at regular intervals concerning how the radio spectrum is managed and administered in Europe.

Recommendation 4.5: The process of conducting theoretical technical compatibility analyses should continue under the auspices of CEPT ECC and its relevant constituent bodies.

Recommendation 4.6: The Commission should consider providing practical and financial support to the process referred to in Recommendation 4.5.

Recommendation 4.7: Consideration should be given to forming an independent EU 'Spectrum Advisory Board' to provide advice to the Commission in complement to the CEPT activities. The proposed European Electronic Communications Market Authority (EECMA) could fulfil this role.

Recommendation 4.8: Vulnerability techniques should be considered as appropriate in future compatibility studies.

Recommendation 4.9: Consideration should be given by the Commission to offering the services of the Joint Research Centre to conduct laboratory and field measurements in support of compatibility analyses.

Recommendation 4.10: A public consultation exercise managed by ERO should be considered as part of any significant proposal for spectrum sharing.

Recommendation 4.11: The option to involve the private sector to undertake the analyses should be considered further if difficulties remain, in which case European standardisation bodies and an 'impartial ERO' should not be excluded from responding to any tender initiative to conduct compatibility studies.

Recommendation 4.12: Any consideration for looking at a general increase in power levels for short range devices should take into account the important differences between the regulatory environments in Europe and the United States, especially in relation to the enforcement of the non-interference requirement.

Recommendation 5.1: To maintain coherence with the other recommendations of this report, the Authorisation Directive should be amended to take account of the following:

- the definition of harmful interference proposed elsewhere in this report (section 3.4.1);
- clarification of harmful interference as a particular class of electromagnetic disturbance for which special putting-into-service and enforcement provisions are available;
- elimination of similar terms to "harmful interference" and "electromagnetic disturbance" which are not defined;
- specific references to the new EMC Directive 2004/108/EC; and
- recognition that harmful interference may arise from sources other than electronic communications systems using radio equipment.

Recommendation 5.2: The R&TTE Directive should be amended to accommodate the following specific points:

- the definition of harmful interference proposed in this report (section 3.4.1);
- the new EMC Directive 2004/108/EC, in particular to make explicit reference to the full essential requirements for electromagnetic compatibility and the specific provisions for fixed installations;
- clarification of harmful interference as a particular class of electromagnetic disturbance for which special putting-into-service and enforcement provisions are available;
- recognition that harmful interference may arise from sources other than radio equipment;
- refocusing the essential requirement exclusive to radio equipment on efficient and appropriate use of the spectrum only;

- recognising the role of technical implementing measures under Decision 676/2002/EC (the Radio Spectrum Decision) as applicable Community legislation for the purposes of defining harmful inference and hence a means of "fine tuning" the harmful interference definition on a case-by-case basis; and
- elimination of terms similar to "harmful interference" which are not defined.

Recommendation 5.3: Concerted efforts should be made to concentrate the specification of technical harmful interference parameters in the Commission mandated measures of Harmonised Standards under the R&TTE Directive and Technical Implementing Measures (Commission Decisions) under the Radio Spectrum Decision.

Recommendation 5.4: The use of radio interface definitions and interface regulations, definitions of the sub-classes of Equipment Class 1 and authorisation (licence) conditions for such technical parameters should be avoided to the maximum extent possible and, in the case of licence exempt use of spectrum "commons", avoided altogether. This includes, other than by cross reference, the repetition of parameters in the mandated measure in order to avoid confusion caused by failure to keep the numerical values of all such citations "in step".

Recommendation 6.1: Technology neutral spectrum masks could be successfully used to define basic spectrum access parameters especially for block licences. Such a mask should be adapted regularly to take into account new technological advances. Beyond this a much more sophisticated method of interference optimisation would provide greater possibility of spectrum efficiency.

Recommendation 6.2: It would not be in the interest of economically efficient spectrum use for the Commission to introduce mandatory technical specifications for receivers.

Recommendation 6.3: For many commercial services, the existing interference environment could be made more harsh without significant economic disadvantages for such services. The Commission should therefore identify services and uses where a relaxation in interference planning criteria could be made to the benefit of enhanced spectrum utilisation.

Recommendation 6.4: The Commission should work towards achieving an interference management regime which:

- enables flexible spectrum use and spectrum sharing between services and operators by using licence terms that do not imply a certain technology;
- works towards low power, small cell services wherever possible in order to allow for better usage of the band edges, both in terms of frequency and area;
- allows spectrum users direct gains from effective spectrum usage and sharing;
- ensures continuity at licence area borders for users in adjacent areas by defining technology independent border conditions where possible;
- considers technology constraints while determining border conditions and licence area sizes; and
- revisits the definitions on a regular basis in order to consider the current state of technology both in transmitter and receiver technology as well as in accurate compatibility analysis.

0.3 Structure of this Report

This document represents the final report on the project 'Study on Radio Interference Regulatory Models in the European Commission'. **The opinions expressed in this study are those of the authors (Eurostrategies and LS telcom) and do not necessarily reflect the views of the European Commission.**

The purpose of this report is to:

- Analyse the key issues identified during the project;
- Propose a set of concrete recommendations for changes in the way in which spectrum management could be handled in the European Union.

The report contains seven sections and eight annexes:

- Section 1 - Introduction:
- Section 2 reviews the framework for spectrum management in Europe to provide the overall regulatory constraints into which any solution should fit.
- Section 3 discusses interference terminology and definitions and concludes with a way towards rationalising and standardising existing definitions.
- Section 4 re-examines the compatibility studies conducted by CEPT for the European Commission identifying areas and ways in which these studies could be made more technically transparent.
- Section 5 analyses some legal issues surrounding existing interference legislation and regulations.
- Section 6 looks at the role of technology in interference management and details a number of analyses to understand the impact of interference management techniques in various scenarios.
- Section 7 examines approaches adopted in other industries towards managing change and their applicability to interference management.
- Annex A provides a glossary of abbreviations.
- Annex B analyses CEPT reports relating to ECC studies.
- Annexes C and D provide examples of ways in which interference information has been effectively presented to consumers.
- Annex E gives some indicative changes required in the key Directives etc to accommodate the recommendations made in the body of the report.

- Annex F discusses the technical aspects of interference control as used in licensing.
- Annex G contains 4 case studies on the implications of tightening receiver characteristics for UMTS, GSM, Digital Fixed Links and for Digital Terrestrial Television.
- Annex H analyses the impacts of spectrum sharing both in and outside of a defined geographic area.

1. Introduction

Through this study, the European Commission has sought to gather information and ideas on how to apply innovative approaches to the fundamental requirement of avoiding harmful interference between different radio systems. The study analyses current interference avoidance mechanisms, and identifies concrete technical, procedural and regulatory steps to assist the EU to optimise such mechanisms so as to exploit fully the potential of wireless technologies for the benefit of European society.

1.1 Background

Spectrum management is fundamentally a way of managing interference. If interference did not occur, there would be no need for restrictions or for detailed planning of spectrum usage and as many users as wished to would be able to access all of the radio spectrum simultaneously.

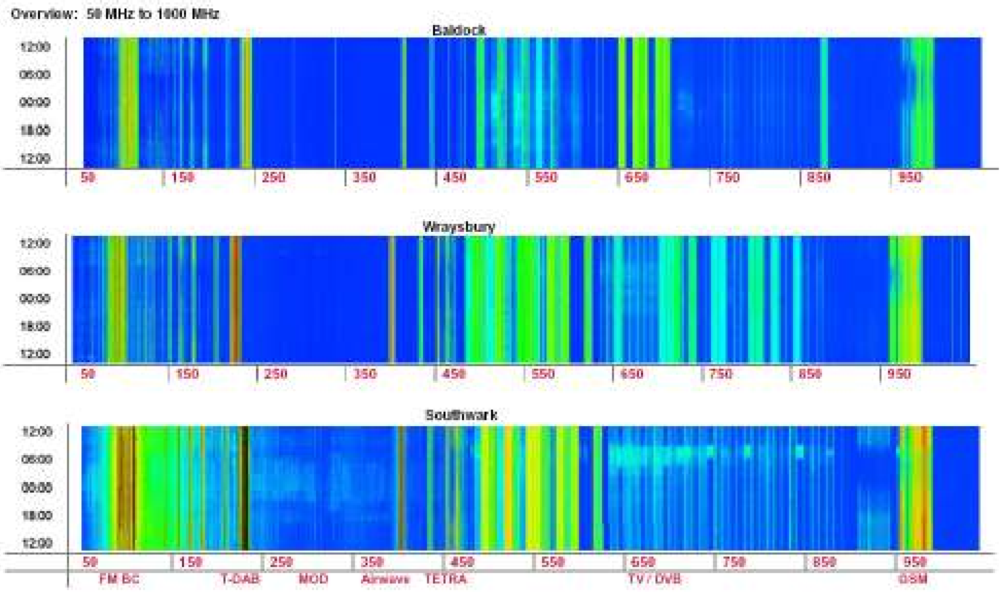
Spectrum management initially began by separating all users from each other either geographically or in terms of their frequency (spectrographically). This simple method for minimising interference and was applied conservatively due to the poor characteristics of the transmitters and receivers available at the time. With the demand for more capacity and increasingly complex types of service to be transported, a separation into different, service-defined frequency bands took place. The majority of radio spectrum is allocated on the basis of a primary user, who has the right to use the spectrum and an expectation that they will not suffer 'harmful' interference. Secondary users may then share the spectrum but must accept interference from the primary user (and not cause interference to it) while generally having protection from interference from other secondary users. There is then a third or tertiary class of user who has no protection whatsoever from any other user and must not cause interference to any other user. Such sharing arrangements are generally detailed in a Table of Frequency Allocations.

Many regard the current level of spectrum utilisation within the European Union as well as worldwide as unsatisfactorily low. Due to physical (propagation) limitations the range of *good useable frequencies*, for most mobile or portable applications, extends from about 70 MHz up to about 5 GHz. Large blocks of this band are occupied by legacy services such as analogue TV, FM broadcasting, traditional land and aeronautical mobile services and the military. What's more, the technologies used by these users are often 30 or more years old and thus spectrally inefficient compared to modern technologies. In order to protect these aged technologies from interference, rules for protection have been set up which can result in inefficient usage of the spectrum. Furthermore, the widespread use of 'first come first served' frequency assignment strategy has resulted in a compromised (a semi-optimal) arrangement from a frequency economy point of view.

Conversely, new technologies show substantial need for bandwidth in order to fulfil the ever increasing demands of the public for mobile and portable communication services. Industry will only invest in new technology where it sees that there will be equitable and predictable access to suitable spectrum. Not all of these new technologies can operate successfully as secondary or tertiary services with no protection against existing users in the band or honour the requirement not to interfere under any circumstances with the primary services.

The continued application of long outdated standards for interference avoidance appears anachronistic. A typical example is the protection of FM reception which is based on the use of a directional antenna at a height of 10m with receiver filter curves based on technologies of the early 1980s. Meanwhile the majority of users prefer mobile or portable receivers using a short, integral antenna, whilst receiver technology far exceeds the performance of the equipment against which the standards were set in the 1980s.

A review conducted by Ofcom[1] in the UK attempted to identify the degree to which spectrum was occupied at various urban, suburban and rural areas in and around London (lower, middle and upper plots respectively). The following diagram illustrates their findings where blue represents no signal and red represents a strong signal. The plot shows occupancy over a 24 hour period.



Source: OFCOM, UK

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[1] http://www.ofcom.org.uk/consult/condocs/sfr/sfr2/sfr.pdf

It is immediately apparent that large swathes of spectrum (even in urban London) remain largely unoccupied over the 24 hour period. Similar experiments in the USA have provided similar outcomes. It could therefore be argued that existing spectrum management techniques are not serving to maximise the occupancy of the spectrum and therefore maximise its value and that, as such, new management techniques are required. One implication of this may be that the parameters used in compatibility studies may be too conservative. Alternatively, there may be insufficient sharing between users, or a too rigid system of control.

The concept of managing spectrum in a different way is embodied in the WAPECS initiative. Wireless Access Policy for Electronic Communications Services[2] relates to platforms used for radio access to electronic communication networks and services, regardless of the bands in which they operate or the technology they use. WAPECS provides for mobile, portable or fixed access to a range of electronic communications services. WAPECS applications may be either licensed or unlicensed, which means that the term encompasses all second and third-generation mobile communications services, wireless data transmission services and WLAN/WiFi as well as broadcasting and TV services.

This policy represents a deliberate attempt to move away from restrictive historical definitions. As convergence between telecommunications and broadcasting, and between cellular telephony and broadband data systems continues apace, the distinction between the ITU definitions of mobile, broadcasting and even fixed are becoming increasingly blurred and even irrelevant. The objective of WAPECS is to enable the frequency bands in question to be used by efficient, digital applications, while at the same time taking account of frequency restrictions designed to permit co-existence. One of the first questions to be resolved in connection with the implementation of the WAPECS concept concerns the restrictions that the spectrum regulator must impose on the frequency bands in order to enable this more liberalised approach, and this study has examined these issues.

1.2 Overview

Managing the radio spectrum and managing interference have always been linked. The use of the radio spectrum has the potential to cause interference and interference can impede the operation of radio equipment. There is clearly a sense of cause and effect. Radio transmissions are the cause and interference is the effect. However, most spectrum management techniques aim to control the causes of radio interference rather than control the effects. Restrictions on transmitter powers, or antenna directionality, and many other techniques are typically employed in order to try and ensure that radio transmitters do not cause undue interference.

[2] Opinion RSPG05-102

In recent years, there has been a slow move towards recognising that it is not the transmission (or reception) parameters per-se that determine the effectiveness of a given spectrum management technique, but that it is sufficient and appropriate to instead impose restrictions on interference. Several regulatory techniques have been proposed and some even implemented. Techniques such as out-of-band emission masks and power flux density based emission limits attempt to address the effects of interference instead of directly controlling the causes.

Technology has also played a part in attempting to deal with the radio environment from the interference perspective; systems have been developed which mitigate against interference or allow operation of radio systems in a situation where potentially harmful interference exists.

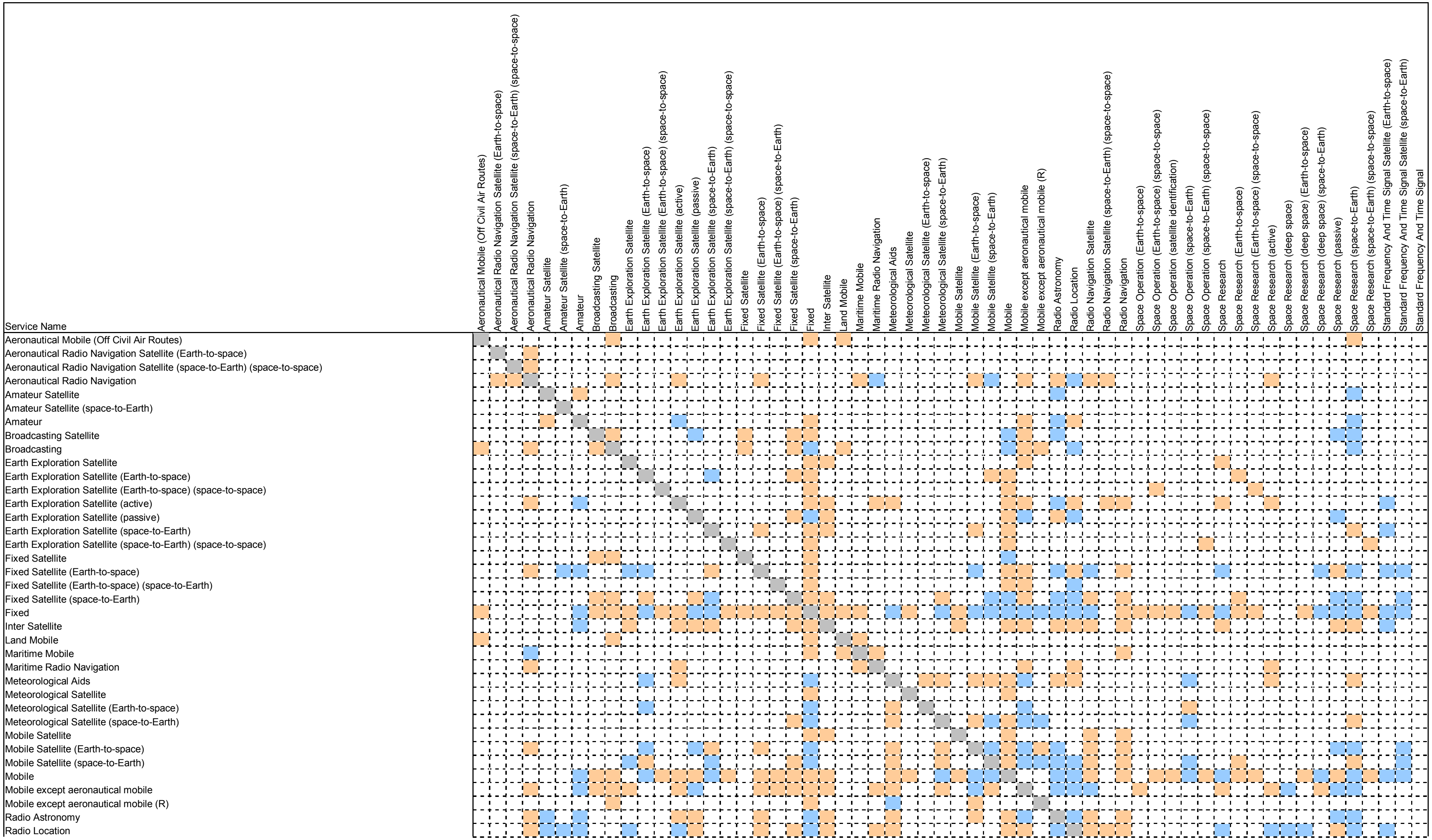
It is, therefore, clearly worth considering whether spectrum management can be undertaken through the management of the effect, i.e. interference, instead of management of the cause, i.e. radio transmitters (and receivers). This possibility is the core tenet which is to be tested during this project, i.e.:

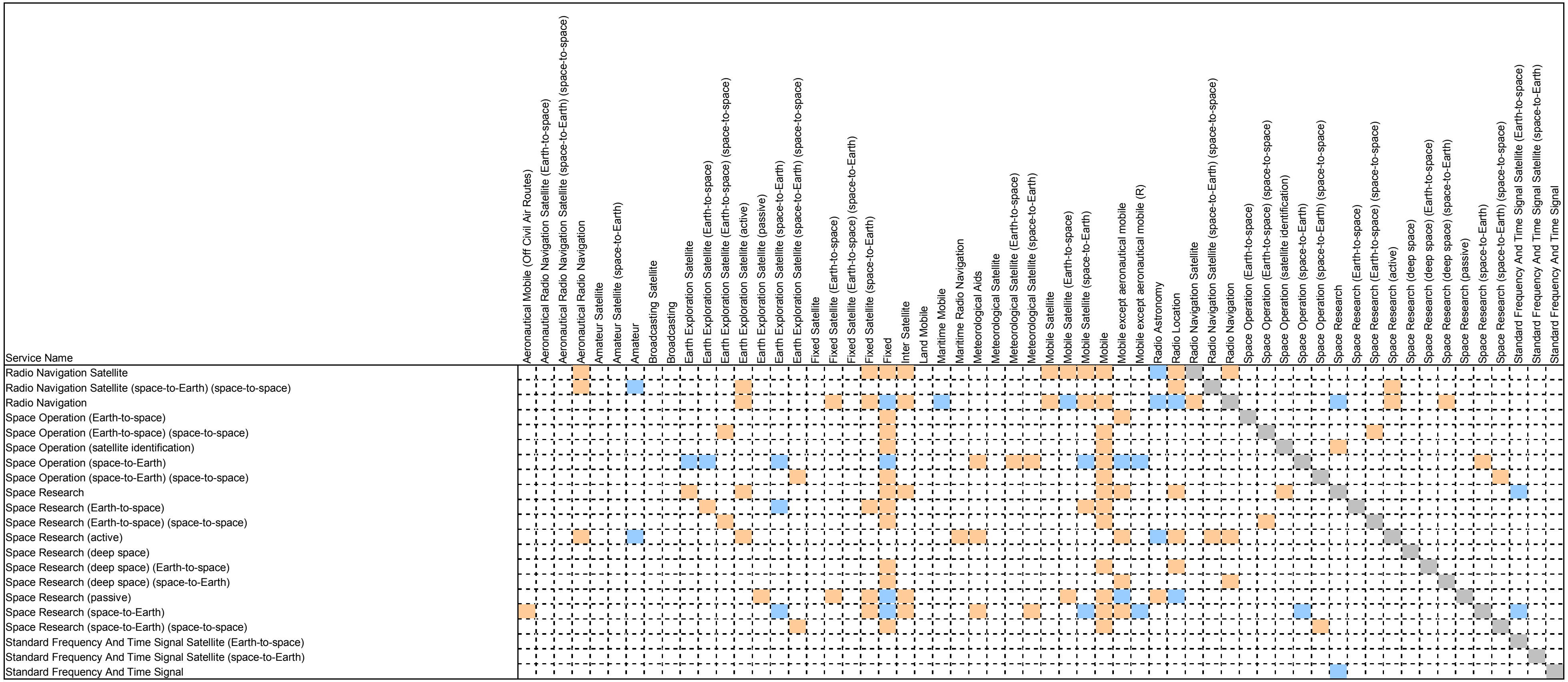
Can spectrum use be made more effective by spectrum management techniques which control interference instead of controlling transmitters?

1.3 The Case for a New Approach

In an attempt to identify some of the potential flaws or anomalies in the existing licensing regime, a straightforward analysis of the ITU region 1 frequency allocation table which covers spectrum usage in Europe (as well as the former Soviet Union, Mongolia, Africa and the Middle East but excluding Iran), shows that there are some services which, at one point in the spectrum or another, share spectrum with almost all other services. Equally there are some services which do not share spectrum with any other service. This would tend to suggest that some services are more capable of dealing with radio interference than others. These services can cope in a complex environment where other users may be present, whereas other services must operate in spectrum that is almost completely free of interference.

The table below illustrates the results of this analysis. The first column lists all services that have been included in the analysis. For the analysis, the frequency bands where these services have primary allocations have been identified and checked against other allocations. The result of this check is given for each service in the subsequent fields of the row. An orange field means that the service listed in the header of the column also has a primary allocation to the band. Blue fields indicate a secondary allocation.


Service Name
Aeronautical Mobile (Off Civil Air Routes)
Aeronautical Radio Navigation Satellite (Earth-to-space)
Aeronautical Radio Navigation Satellite (space-to-Earth) (space-to-space)
Aeronautical Radio Navigation
Amateur Satellite
Amateur Satellite (space-to-Earth)
Amateur
Broadcasting Satellite
Broadcasting
Earth Exploration Satellite
Earth Exploration Satellite (Earth-to-space)
Earth Exploration Satellite (Earth-to-space) (space-to-space)
Earth Exploration Satellite (active)
Earth Exploration Satellite (passive)
Earth Exploration Satellite (space-to-Earth)
Earth Exploration Satellite (space-to-Earth) (space-to-space)
Fixed Satellite
Fixed Satellite (Earth-to-space)
Fixed Satellite (Earth-to-space) (space-to-Earth)
Fixed Satellite (space-to-Earth)
Fixed
Inter Satellite
Land Mobile
Maritime Mobile
Maritime Radio Navigation
Meteorological Aids
Meteorological Satellite
Meteorological Satellite (Earth-to-space)
Meteorological Satellite (space-to-Earth)
Mobile Satellite
Mobile Satellite (Earth-to-space)
Mobile Satellite (space-to-Earth)
Mobile
Mobile except aeronautical mobile
Mobile except aeronautical mobile (R)
Radio Astronomy
Radio Location
Radio Navigation Satellite
Radio Navigation Satellite (space-to-Earth) (space-to-space)
Radio Navigation
Space Operation (Earth-to-space)
Space Operation (Earth-to-space) (space-to-space)
Space Operation (satellite identification)
Space Operation (space-to-Earth)
Space Operation (space-to-Earth) (space-to-space)
Space Research
Space Research (Earth-to-space)
Space Research (Earth-to-space) (space-to-space)
Space Research (active)
Space Research (deep space)
Space Research (deep space) (Earth-to-space)
Space Research (deep space) (space-to-Earth)
Space Research (passive)
Space Research (space-to-Earth)
Space Research (space-to-Earth) (space-to-space)
Standard Frequency And Time Signal Satellite (Earth-to-space)
Standard Frequency And Time Signal Satellite (space-to-Earth)
Standard Frequency And Time Signal


Service Name
Aeronautical Mobile (Off Civil Air Routes)
Aeronautical Radio Navigation Satellite (Earth-to-space)
Aeronautical Radio Navigation Satellite (space-to-Earth) (space-to-space)
Aeronautical Radio Navigation
Amateur Satellite
Amateur Satellite (space-to-Earth)
Amateur
Broadcasting Satellite
Broadcasting
Earth Exploration Satellite
Earth Exploration Satellite (Earth-to-space)
Earth Exploration Satellite (Earth-to-space) (space-to-space)
Earth Exploration Satellite (active)
Earth Exploration Satellite (passive)
Earth Exploration Satellite (space-to-Earth)
Earth Exploration Satellite (space-to-Earth) (space-to-space)
Fixed Satellite
Fixed Satellite (Earth-to-space)
Fixed Satellite (Earth-to-space) (space-to-Earth)
Fixed Satellite (space-to-Earth)
Fixed
Inter Satellite
Land Mobile
Maritime Mobile
Maritime Radio Navigation
Meteorological Aids
Meteorological Satellite
Meteorological Satellite (Earth-to-space)
Meteorological Satellite (space-to-Earth)
Mobile Satellite
Mobile Satellite (Earth-to-space)
Mobile Satellite (space-to-Earth)
Mobile
Mobile except aeronautical mobile
Mobile except aeronautical mobile (R)
Radio Astronomy
Radio Location
Radio Navigation Satellite
Radio Navigation Satellite (space-to-Earth) (space-to-space)
Radio Navigation
Space Operation (Earth-to-space)
Space Operation (Earth-to-space) (space-to-space)
Space Operation (satellite identification)
Space Operation (space-to-Earth)
Space Operation (space-to-Earth) (space-to-space)
Space Research
Space Research (Earth-to-space)
Space Research (Earth-to-space) (space-to-space)
Space Research (active)
Space Research (deep space)
Space Research (deep space) (Earth-to-space)
Space Research (deep space) (space-to-Earth)
Space Research (passive)
Space Research (space-to-Earth)
Space Research (space-to-Earth) (space-to-space)
Standard Frequency And Time Signal Satellite (Earth-to-space)
Standard Frequency And Time Signal Satellite (space-to-Earth)
Standard Frequency And Time Signal
Radio Navigation Satellite
Radio Navigation Satellite (space-to-Earth) (space-to-space)
Radio Navigation
Space Operation (Earth-to-space)
Space Operation (Earth-to-space) (space-to-space)
Space Operation (satellite identification)
Space Operation (space-to-Earth)
Space Operation (space-to-Earth) (space-to-space)
Space Research
Space Research (Earth-to-space)
Space Research (Earth-to-space) (space-to-space)
Space Research (active)
Space Research (deep space)
Space Research (deep space) (Earth-to-space)
Space Research (deep space) (space-to-Earth)
Space Research (passive)
Space Research (space-to-Earth)
Space Research (space-to-Earth) (space-to-space)
Standard Frequency And Time Signal Satellite (Earth-to-space)
Standard Frequency And Time Signal Satellite (space-to-Earth)
Standard Frequency And Time Signal

It is clear that some services, notably the fixed and mobile services, at some frequency or other, share spectrum with many (if not most) of the other radiocommunication services listed in the table. Obviously this does not hold true for all frequency bands and the propagation characteristics of some frequencies enables such sharing in some bands but not others. However, it may indicate that there is greater scope for such services to share in other frequency bands or, one may even argue that, instead of detailing which bands a service may share with, one should instead just list the services it can share with.

Conversely other services, such as standard frequency and time, share spectrum with virtually no other services.

What this analysis therefore attempts to highlight is that, even within existing spectrum regulation, there are opportunities for considering alternative ways in which managing spectrum might be handled. Whilst a wholesale move to a sharing based management regime might not be internationally accepted (and would still rely on bands with primary users, sharing and so forth), it is clear that there may be greater potential for relaxing controls than at first may appear.

1.4 Interference Management Techniques

Whilst the case for a new approach is clear, the exact nature of such an approach is not so obvious. A number of different spectrum management techniques have been proposed which differ in the way in which they deal with splitting the spectrum between users and could be considered interference management techniques. Below we describe a few examples of such techniques:

- **Management by Service Type:** Within the existing ITU spectrum management framework, there are certain services which share spectrum with other services (on a co-primary or on a primary-secondary basis) in one band or another. The fact that such sharing is or has been allowed is based on sharing, compatibility and other such studies. Whilst there are obviously differences in the propagation characteristics of some bands relative to others, there could be scope to expand the bands in which sharing between already sharing services takes place. As such, each band or sub-band in a frequency allocation table could be allocated to one or more primary services. For each of these services a look-up table could be used to identify which other services can share on a co-primary or secondary basis. As the sharing arrangements have already been determined for such cases, this would potentially open up bands for use by many more services and applications than the current allocations, without any change in the sharing criteria used.

- **Management by Power Level:** Another alternative to the traditional spectrum management approach might be to licence users not by means of the services they are using but by means of the power they are transmitting. In such a scenario, instead of being split into service specific bands, the spectrum might be divided up into bands where low, medium and high power services existed.[3]

- **Management by Interference Neighbourhood:** Similarly to dividing the spectrum up by the transmitted power, it could be divided up on the basis of the amount of interference one could expect to encounter in using a specific piece of spectrum. Thus the spectrum might be specified in terms of low, medium or high 'interference neighbourhoods' whereby the level of interference is specified. Of course this has no direct correlation to the amount of interference that might be generated by the services in those bands, though it would restrict the amount of interference that should end up in adjacent neighbourhoods.

  A combination of power level and interference neighbourhood might be a viable system, ensuring that low interference neighbourhoods were not adjacent to high power services which may cause problems even if the level of interference they produced was tiny due to blocking and in-band interference effects.

- **Management by Occupied Bandwidth:** Different technologies require different amounts of radio bandwidth. Today's wideband applications can use upwards of 10 MHz of spectrum (UWB is perhaps an extreme exception which can utilise several GHz of spectrum), whereas narrowband communications may require no more than 15 kHz (and sometimes significantly less). Furthermore the sharing opportunities between wideband and narrowband systems are many and varied. Some wideband systems can tolerate a certain amount of narrowband interference and vice versa. The immunity of the technologies depends on both the technology itself and the relative levels of interference.

  One way of managing spectrum might therefore be to divide it up between systems requiring different bandwidths, together with some control over the relative levels of interference. For example, a high power wideband band may permit the use of low power narrowband systems in the same spectrum and vice versa.

- **Market-Based Frequency Allocation and Assignment:** With the advent of software-defined and cognitive radios, other advanced technologies and the use of market-based assignment and allocation, it is possible to envisage a scenario where radio users themselves (or even the equipment they are using) select the appropriate spectrum, power, modulation scheme and so on – in effect using some or all of the above management techniques simultaneously and dynamically. In such a scenario, decisions on acceptable interference levels and how much can be caused to neighbouring systems would be taken on-the-fly as services and applications were required to communicate.

[3] This concept is explored in the book 'Essentials of Modern Spectrum Management', by Webb, Cave and Doyle, and shown to offer no significant benefit compared with existing techniques.

This is not an anarchic situation where everyone fends for himself, but is one in which the traditional distinctions between different spectrum usages and users have been largely removed, allowing radio transmitters and receivers to roam freely around the spectrum as required and as suitable. There are certain analogies between this situation and today's licence-exempt bands, although the controls on licence-exempt usage may be more stringent in some ways (and less stringent in others) than might be envisaged here.

- **Scorched-Node Re-Planning:** If one were to analyse the frequencies used for services and compare these to the optimum that those services would ideally use, one might find that many of the frequencies in use for services are sub-optimal. A thorough re-planning of the whole spectrum might bring about wholesale and overarching improvements in spectrum usage and, more importantly, might free spectrum for those services where demand is increasing. Re-planning a resource where certain points are fixed is usually called a scorched node approach in that whilst some 'nodes' have to remain intact, the rest of the landscape can be burnt to the ground to make way for a new outlook. A scorched node re-planning of the radio spectrum may yield some interesting possibilities if a new spectrum topology presents itself or if the existing topology proves to be relatively efficient when all constraints are taken into account.

  Such a re-planning exercise, however, would need to take account of some of the real-life restrictions that exist. For example:

  - Certain frequencies have unique characteristics. Radio-astronomy, for example, makes use of spectral lines which exist due to radiation from certain elements (the hydrogen line at 1420.406 MHz for example). If these frequencies were not available for radio-astronomy, the opportunity for study would be completely lost.

  - Certain services have exceptionally large equipment user bases. Taking the example of FM broadcasting, if one assumes that there is one receiver per individual in Europe, then upwards of 500 million FM radio receivers are in use today. Changing the bands used for these services would entail a massive re-fitting and replacement of equipment. Similar situations might exist for other broadcasting bands as well as cellular services (though it is interesting to note that the move to 3G spectrum from existing 2G GSM spectrum, whilst still relatively slow, is expected to accelerate over coming years and the potential replacement cycle for cellular networks is fast at 2 to 3 years).

  Other restrictions on the use of certain frequencies for certain services or applications may also exist. The fact that different frequencies have different propagation characteristics is also important in considering how usage might change, although it is this factor which tended to drive certain services to certain frequencies to begin with.

These conceptual techniques represent several alternative ways in which the spectrum could be managed, although a more realisable approach is necessary for any analysis to be conducted. We have therefore tried to identify common themes between these techniques to which we can then apply a technical analysis to determine the degree to which such techniques might provide benefits above and beyond existing management systems. We have therefore explored the following central themes:

- **Tightening of Receiver Characteristics:** Traditional spectrum management deals mostly with specifying transmitter characteristics. However interference management techniques may also require receiver characteristics to be specified (i.e. the regulation of receivers instead of, or in addition to, that of transmitters).

- **Technology and Service Neutrality:** Operating different services or technologies in adjacent areas or in adjacent spectrum represents one of the biggest changes in an interference managed world compared to more traditional approaches.

These two themes have been analysed in depth as an exploration of the implications of interference management.

1.4.1 Licensed versus Licence-Exempt Spectrum Usage

Whilst the concepts of interference management apply well in situations where spectrum usage is licensed, the application of such techniques to licence-exempt spectrum usage is more complex. Interference management requires clear rules for dispute resolution preferably under control of a single manager whose responsibility is to ensure that any interference parameters for any particular piece of spectrum (and its neighbours) are not contravened. In a licence-exempt situation, the cumulative effect of users would be out of the hands of any one controller and whilst equipment specification and certification could be used to attempt to limit the amount of interference produced, there would be no way for an individual user to know whether the addition of their emissions to the interference ‘smog’ generated would mean that some overall level would be exceeded. Nor would there be any straightforward way for the manager to control individual users to reduce the total amount of smog produced.

Clearly, controls could be introduced on the equipment and applications which could use the spectrum. However any interference prediction relies on some knowledge of the likely level of usage. If usage is under-predicted then excess interference could arise; but, equally, if over-conservative assumptions were taken into account then spectrum usage would not be fully effective.

The results of our study of interference management are therefore more directly applicable to licensed spectrum usage than licence exempt usage. In considering interference management techniques in unlicensed spectrum, ways of controlling the smog therein produced, particularly when critical levels are reached and local collapse is imminent, have to be balanced against the need for any specific control.

2. Framework for European Spectrum Management

2.1 International Telecommunication Union (ITU)

At the global level, spectrum use is essentially managed within the framework of the ITU. The ITU is a specialised agency of the United Nations and has *inter alia*, the role of ensuring the equitable and efficient use of spectrum and orbital resources for satellite communications. Through a process of regular World Radiocommunication Conferences (WRC), the ITU establishes and reviews an overall framework for spectrum management and regulation, which is embodied in the Radio Regulations (RR), a document having treaty status. The RR provide the basis for national and regional standards and regulations.

The major components of the RR are:

- **Definition of all terms concerning transmitters, frequencies, services, allocations, and assignments;**
- **Frequency allocation table detailing how the spectrum may be utilised;**
- **Call sign allocations;**
- **International services and their characteristics; and**
- **International coordination and ITU notification.**

In using the radio frequency spectrum, Member States of the ITU are required:

- to endeavour to limit the number of frequencies and the spectrum used to the minimum essential to provide the necessary services and to apply the latest technical advances as soon as possible; and

- to bear in mind that spectrum and orbit resources are limited and that they must be used rationally, efficiently and economically in conformity with the RR so that countries may have equitable access to said resources. It is further required that all stations must be operated in such a manner as not to cause harmful interference to the authorised radio services of other Member States which operate in accordance with the RR.

The RR therefore set out to:

- facilitate equitable access to and rational use of spectrum and orbit resources;
- ensure the availability and protection from harmful interference, of frequencies provided for distress and safety purposes;
- assist in the prevention and resolution of cases of harmful interference between the radio services of different administrations;
- facilitate the efficient and effective operation of all radiocommunication services; and
- provide for and, where necessary, regulate new applications of radiocommunication technology.

The underlying principle of the RR is primarily the pre-emptive avoidance of, and protection against, harmful interference particularly in respect of safety radiocommunication services which are used permanently or temporarily for the safeguarding of human life and property. The RR also seek to facilitate services of an international nature, for example maritime, aeronautical and space radiocommunications. To date the key tool to implement the principle of mitigating harmful interference is the harmonisation of frequency allocations to various generic radiocommunication services as documented in the International Table of Frequency Allocations, Article 5 of the RR.

2.1.1 Table(s) of Frequency Allocations

There are three tiers of such tables in the European region. At the international or ITU level the table is embodied in the ITU RR (ITU Region 1 table). For the European regional situation, the European common table of frequency allocation and utilisations (ECA) appears as ERC Report 25 of the European Conference of Postal and Telecommunications administrations (CEPT). European Union (EU) Member States will also have a national frequency table where National Regulatory Authorities (NRA) will define the arrangements and status for sharing spectrum at the national level between radio services and between user categories.

The Table of Frequency Allocations (FAT) in the ITU RR contains details of how spectrum is to be divided up between different generic radiocommunications services. The radiocommunication service definitions are technologically neutral and of a generic nature; typical examples are Radio Astronomy, Mobile, Fixed, Fixed-Satellite and Broadcasting. Frequency allocations are bands of radio frequencies which have been identified for use by particular radiocommunication services. As illustrated in section 1.3 above, there are only a few frequency bands throughout the entire spectrum which are allocated exclusively to a single radiocommunication service and in most cases frequency bands are shared by several services. The conditions for sharing a frequency band are regulated by technical compatibility rules decided after extensive studies and discussions between administrations. These are often adopted at an ITU WRC as amendments to the RR. The FAT identifies, for each block of spectrum, what the primary and secondary use services are. There are three tables, corresponding to the three ITU regions of the world, which set the framework for all spectrum usage.

The above division of spectrum between radiocommunication services is either on a co-primary basis, where all users have an equal right to use the spectrum, or on a primary/secondary basis, where one service has priority use over another. In both cases operation in the band is possible for systems falling within the service definition; however the manner in which a system is protected against interference depends on the status of the allocation afforded to it (primary or secondary).

- Systems operating on a primary basis are protected against interference from future systems of a primary or secondary service operating in the same frequency band. They are also protected against interference from existing systems operating on a secondary basis.

- Subsequent systems operating on a primary basis are protected against all secondary systems but not with respect to existing (agreed and co-ordinated) primary systems.

- Systems in a service having secondary status must not cause harmful interference to systems of a primary service; they are also not protected from interference from current or future stations of a primary service. However they are protected against interference from future stations of a secondary service.

- There are also tertiary uses of spectrum where no protection from interference is given, nor must any interference be caused by tertiary status use to primary or secondary services. This is often referred to as operation on a 'non interference basis (NIB)'.

Radio waves do not respect international borders and in order to avoid interference, co-ordination takes place between States at various levels:

- Coordination at the global level (ITU);
- Coordination at the European level (CEPT/ECC, EU);
- Coordination between individual States (NRA);
- Coordination within a country, between sector interests e.g. governmental, non-governmental services (NRA); and
- Coordination between users in a certain sector (NRA or a body with delegated spectrum management authority).

International frequency coordination agreements are often based on equal access to spectrum on either side of an international border. Such agreements can lead to difficulties where there is a major conurbation on one side of the border and a predominately rural area on the other side.

2.1.2 Assignment and use of Frequencies

As indicated above, the ITU FAT is included in Article 5 of the RR which is entitled "Frequency Allocations". Article 4 of the RR deals with "Assignment and use of Frequencies" and contains regulatory text regarding interference which is particularly relevant in the context of this study:

> Any new assignment or any change of frequency or other basic characteristic of an existing assignment (see Appendix 4) shall be made in such a way as to avoid causing harmful interference to services rendered by stations using frequencies assigned in accordance with the Table of Frequency Allocations in this Chapter and the other provisions of these Regulations, the characteristics of which assignments are recorded in the Master International Frequency Register.
>
> *Article 4.3*

> Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations.
>
> *Article 4.4*

Frequency assignments to stations are recorded and maintained in the Master International Frequency Register. Frequency assignments recorded in the Master International Frequency Register are protected against interference according to their status as stations of a primary or secondary service.

It is worth noting that the RR do not give detailed instructions to national administrations on how to achieve "working" band plans or the resolution of interference issues, but rather provides a high level framework. In particular the definition of harmful interference is, as described earlier, not sufficiently detailed to allow the generation of methods and technical parameters required to assess interference.

The RR are complemented by diverse recommendations that are approved by ITU Members in specialised groups of the ITU's Radiocommunications Sector. The recommendations address mainly technical issues, such as standardised propagation and climatic models, coordination procedures for terrestrial broadcast networks and satellite networks etc. In some specific cases, the RR incorporate recommendations by reference and consequentially such recommendations will achieve the same regulatory status as the RR. However, in most cases the recommendations are advisory rather than mandatory; nevertheless in practice most ITU recommendations are generally adopted by National Regulatory Authorities (NRA). They therefore play a significant role in shaping spectrum management activities.

2.2 European Institutions

2.2.1 National Regulatory Authorities (NRA)

At the national level, regulation and planning is carried out by the NRA, which also represents national interests in international forums. Because of differences between countries in economic standing, technological development or as a result of historical circumstances, there could be sub-regional deviations from the ECA that may lead to harmonisation difficulties.

The frequency bands allocated by the ITU, which have been addressed in Europe when considering or revising the ECA, have then to be adopted by the NRA responsible for spectrum management. A national band plan is developed that might be accompanied by rules that define, for example, the method for licensing as well as methods and technical rules for the usage of different bands. Licences are granted to users giving them the right to establish and operate radiocommunications systems and stations. Operating rights might be limited to specific frequencies and specific geographic areas and might further be bound by specified technical conditions in respect of parameters relating to power, band-width and antennas.

2.2.2 CEPT & ECC

Although NRAs of EU Member States cannot take positions in the ITU that go counter to their obligations under the EU Treaties, there is no single voice to represent the interests of the EU in ITU. European positions are co-ordinated within CEPT[4].

One of the main objectives of CEPT is to harmonise frequency usage in Europe, where necessary, in conformance with the RR and any European requirements, based on the principle of efficient use and equitable access to frequencies for all administrations. This facilitates trade and cross-border services as well as simplifying the task of co-ordination if incompatible radiocommunication services were to be operated on opposite sides of a border.

Regulation and spectrum planning are carried out by two regional organizations CEPT and the EU. CEPT has 48 members. These organizations represent regional interests in global forums involved in spectrum management matters. Technical harmonisation measures at the European level are carried out by CEPT's Electronic Communications Committee (ECC), by means of various instruments – CEPT ECC Decisions and Recommendations as well as European Common Proposals to ITU WRCs. CEPT ECC Decisions are not binding on CEPT members although EU Member States within CEPT generally commit themselves to implement CEPT ECC Decisions in writing.

CEPT owes its origins to a close collaboration of the post and telecommunications authorities of a number of European countries which started in 1959. Perhaps surprisingly, it lacks a formal legal corporate "personality" and so, in that sense, has no formal executive authority. The shift from monopoly state providers of communications services to private enterprise depleted direct operational PTT expertise in CEPT leaving it largely as a group of national policy makers and regulatory authorities. It relies heavily on voluntary contributions and consensus building for its success. The presidency rotates on an annual basis and is hosted by the members in turn. An MoU[5] between the European Commission and CEPT was signed in 2004. CEPT enjoys observer status in the EU Radio Spectrum Policy Group and in the Radio Spectrum Committee.

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[4] Conférence Européenne des Postes et Télécommunications www.cept.org

[5] Memorandum of Understanding Between the European Commission ("the Commission") and the European Conference of Postal and Telecommunications Administrations ("CEPT") http://ec.europa.eu/information_society/policy/radio_spectrum/activities/cept_mou_signature.doc

The Electronic Communications Committee (ECC) is a subordinate committee of CEPT dealing with inter alia, efficient use of radio spectrum. It has its own infrastructure of Working Groups and Project teams dealing with regulatory affairs, frequency management and spectrum engineering. The European Commission has "Counsellor" status in CEPT, that is to say it may participate in all meetings of the CEPT with the right to speak but not to vote. Voting members are the members of CEPT, as of right. The Rules of Procedure require that "In carrying out its activities the ECC will establish close cooperation and consultation with relevant European bodies in particular the European Commission and the European Free Trade Association".

A particularly important subject falling within the scope of this project is CEPT ECC's work on spectrum engineering matters. This includes the preparation of detailed compatibility studies between radiocommunication systems, technologies and services, which supports *inter alia* activities such as the ECA, originally due to be completed in 2008, and the co-ordination of frequencies both within and between CEPT member countries. The European Telecommunications Standards Institute (ETSI) also plays an important spectrum engineering role through the standardisation process since a proposal for new radiocommunications devices/systems is normally initiated in ETSI.

2.2.3 ERO

The European Radiocommunications Office (ERO) in Copenhagen is an off-shoot of CEPT initially set up in 1991 under a memorandum of understanding but now given formal status as a legal entity under the Convention for the Establishment of the European Radiocommunications Office (ERO) and a Host Agreement with the Government of Denmark. An amendment to the Convention is currently undergoing ratification by its signatories. This amendment combines functions of the European Telecommunications Office (ETO) with those of the ERO to form the European Communications Office (ECO)[6].

The contracting parties to the Convention represent some 30 countries, extending beyond the EU Member States. Furthermore, some six EU Member States are not contracting parties to the Convention although as members of CEPT they are entitled to be. The purpose of the ECO is to be: "A centre of expertise in postal and electronic communications to assist and advise the CEPT presidency and the CEPT Committees." This purpose is then elaborated in a list of 12 primary functions, mostly directed at CEPT support, but including "8. to liaise with the European Union and with the European Free Trade Association". Amongst the CEPT committees to which assistance and advice are offered is the ECC. The European Commission has the right to participate in the Council of representatives of the Contracting Parties to the Convention with the status of Observer.

[6] The ERO Convention is not publicly available on the ERO website but copies of the amended version currently being presented for ratification to the contracting parties' governments can be found in relevant areas of some Member States public information eg: http://www.anacom.pt/streaming/eco.pdf?categoryId=233984&contentId=453134&field=ATTACHED_FILE (viewed 12 JUN 07).

2.2.4 ETSI & CENELEC

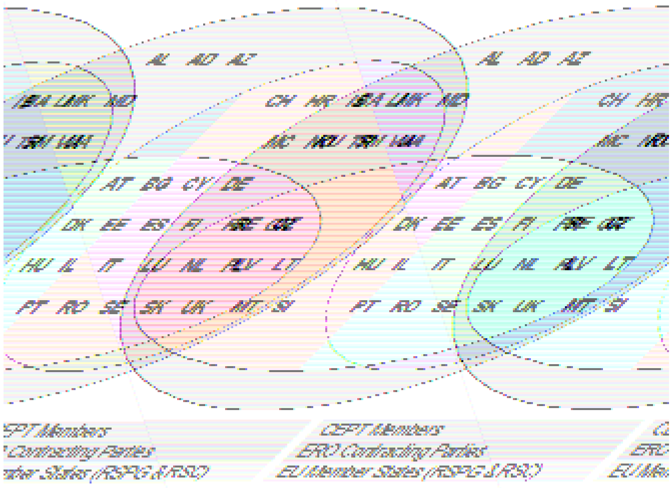
The European Telecommunication Standards Institute (ETSI) has responsibility, in the present context, for preparing standards under mandates from the European Commission which give a presumption of compliance with essential requirements concerning "harmful interference" under the R&TTE Directive. ETSI is also similarly responsible for electromagnetic compatibility standards under the R&TTE Directive and some standards under the EMC Directive.

The European Committee for Electrotechnical Standardisation (CENELEC) has responsibility, in the present context, for preparing standards under mandates from the European Commission which give a presumption of compliance with essential requirements concerning "electromagnetic disturbance" under the EMC Directive as called up by the R&TTE Directive.

Both ETSI and CENELEC are formally recognised under EC Law.

2.2.5 Relationships between CEPT, ERO & NRAs

As explained in the section on Legal Instruments (section 5 below), the European Commission is assisted in implementing radio spectrum policy measures by the Radio Spectrum Policy Group (RSPG) and the Radio Spectrum Committee (RSC). The RSPG, RSC, CEPT and ERO are all supported by National Regulatory Authorities (NRAs). This makes for a complex dynamic illustrated in the figure below:



The all-embracing group, CEPT, has no legal status and relies essentially on voluntary participation and voluntary adoption of its decisions. The RSC relies on CEPT in that the Commission, having first submitted proposals to the RSC, issues mandates to CEPT concerning technical implementing measures under the Radio Spectrum Decision. RSPG and RSC participants reflect Community obligations on Member States in respect of efficient use of the radio spectrum and avoidance of harmful interference. The working relationship Commission-RSC-CEPT is specified formally in the Radio Spectrum Decision (see Section 2.4 below). ERO, as the effective permanent legal entity established by CEPT, acts as a de-facto go-between.

The procedure for Commission Decisions prepared in consultation with the RSC and based on mandates to CEPT under the Radio Spectrum Decision overtakes earlier less-binding Council resolutions[7] encouraging cooperation between Member States and CEPT / ERO.

More recently, Commission Decision 2007/344/EC of 16 May 2007[8] instructs Member States to use the ERO Frequency Information System (EFIS) as a common point for information about use of the radio spectrum.

ERO also manages on a less formal basis the publication of the indicative list of sub-classes of equipment for which the Member States impose no restrictions on putting into service under the R&TTE Directive (see Section 5.2).

Overall, despite the underpinning of some of these relationships with legal measures, the success of the arrangement relies essentially on compromise and consensus. One commentator[9] describes the ERO as a "classic 'rule of multiple Cs' organization' meaning that it relies heavily on consensus, compromise, collaboration, and culture" but, in fact, this is true of the whole arrangement.

The reliance on voluntary resources committed to the ECC by national agencies makes it difficult for Commission mandates to CEPT to engender any sense of urgency, sustain activity or exert any kind of executive control. Nevertheless, the arrangement has generated a number of CEPT mandates and corresponding Commission Decisions[10] in recent years. The question now arises whether the "multiple Cs" of the current synergy will be adequate for the future or will the law of diminishing returns set in. Failure of the "multiple Cs" might frustrate the proper pursuit of Community policy aims by exploiting the particularities of the present structure or national perspectives. Perhaps the recent Commission Decision on the EFIS database provides an indication of how some executive and operational issues might be centralised in a body such as ERO.

2.2.6 Co-operation between CEPT & ETSI

Detailed co-operation arrangements are in place between CEPT and ETSI. The regulatory and standardisation process involved in the introduction of new radiocommunications devices and systems in Europe is briefly as follows.

[7] Council Resolution of 28 June 1990 on the strengthening of the European-wide cooperation on radio frequencies, in particular with regard to services with a pan-European dimension (OJ No C 1666, 7.7.90, p4)
Council Resolution of 19 November 1992 on the implementation in the Community of the European Communications Committee Decisions (OJ No C 318, 4.12..92, p1)

[8] Commission Decision 2007/344/EC of 16 May 2007 on harmonized availability of information regarding spectrum use within the Community (OJ No L 129, 17.5.2007, p67).

[9] Ryan, Patrick S., "European Spectrum Management Principles". Journal of Computer and Information Law, Vol. 23, p. 277, 2005 Available at SSRN: http://ssrn.com/abstract=790904

[10] The Decisions are mostly listed in the "Legal Instruments" section of the report.

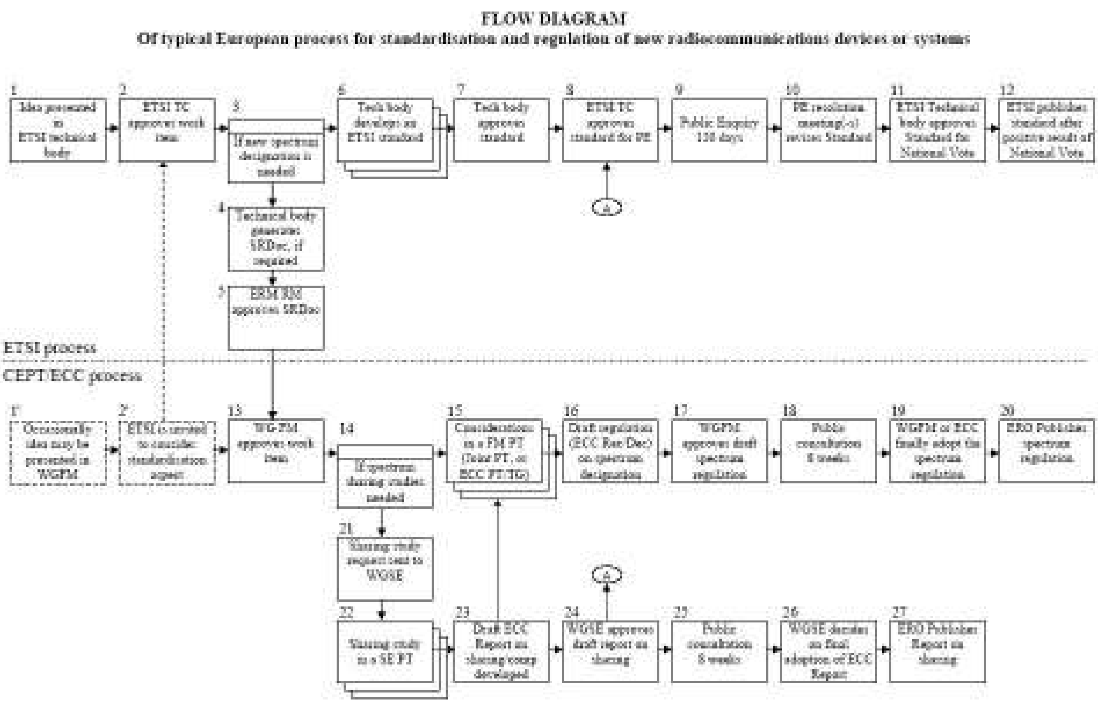
The process is normally started in an ETSI technical group, which meets 3-4 times per year in response to an industry demand. The ETSI group reviews industry inputs and approves a work programme sheet. Although a proposal for new radiocommunications devices/systems is normally initiated in ETSI sometimes such a proposal is first presented within CEPT ECC, typically within the Frequency Management Working Group. In such cases CEPT would inform ETSI about the proposed new work item and would advise the promoter of a new system to initiate development of a European standard through the ETSI mechanisms.

If there is a sharing or compatibility problem or when a new spectrum allocation is required, the originating ETSI technical group generates a System Reference Document (SRDoc) describing the RF characteristics and any RF compatibility issues.

CEPT will analyse the SRDoc and will decide if the ETSI request should be rejected or approved as a new work item. If sharing or compatibility concerns are detected, the Spectrum Engineering Working Group of CEPT is invited to perform the necessary sharing/compatibility studies.

An ECC deliverable may be required (ECC Decision or Recommendation) if a new frequency band is to be designated for the application. The Public consultation of draft ECC deliverables is carried out by CEPT's European Radiocommunications Office (ERO) and lasts for 8 weeks. Any interested party may comment on the proposal by sending their comments directly to ERO.

The ECC-ETSI process is detailed in the diagram below. It does not include the EC dimension, notably the relationship of these organisations with the Commission via the RSC and TCAM committees.



In the case of harmonised standards, which provide manufacturers and importers with a presumption of conformity with the essential requirements of the R&TTE and EMC Directives, the European Commission issues a mandate to ETSI (and other standardisation bodies) to undertake the necessary standardisation work.

This can become a somewhat circular process since national administrations incorporating regulators and spectrum management organisations can also be members of ETSI.

ETSI plays a major role in developing a wide range of standards and other technical documentation as Europe's contribution to world-wide ICT standardization. ETSI's prime objective is to support regional and global harmonization by providing a forum in which all the key players can contribute actively. ETSI's Members determine the Institute’s work programme, allocate resources and approve deliverables with the goal of aligning the organisation’s activities with market needs. ETSI standards are developed by a process of consensus. Much of the necessary co-ordination is conducted at the national level by Member States of CEPT and the EU.

2.2.7 Harmonisation within the EU

The EU currently has 27 member states and regulates the spectrum use with mandatory Decisions and Directives. In some cases, countries outside the EU (for example 3 of the four European Free Trade Association (EFTA) members; Iceland, Lichtenstein and Norway) also adopt these regulations for their spectrum management activities. Seven CEPT members are accession countries to the EU (Turkey, Croatia, Macedonia, Serbia, Montenegro, Albania and Bosnia) with an obligation to implement EU acquis before joining the Union, and are already voluntarily applying some EC Decisions.

Until recently much of Europe’s spectrum usage and plans was a direct legacy of World War II. As military systems were decommissioned, portions of spectrum were released for civil usage. Unfortunately different portions became available in different European countries, which set the scene for the following 30 years. Furthermore, in the post war era, spectrum was used in a different manner across NATO countries, former Warsaw Pact countries and neutral countries. Thus frequency planning developed according to a country’s political affiliation, its economic situation and level of technological development. This resulted in different principles for frequency management, different usage of frequency bands and different technological standards. The European Union and CEPT have realised the need for a common regulatory approach with respect to the radio frequency spectrum, which is classified as a scarce resource. At EU level, this has resulted in the series of comprehensive regulatory measures which were incorporated into its New Regulatory Framework of 2002

2.3 Other International Bodies

As well as the ITU, there are two other United Nations specialised agencies of importance. Annex 10 of the International Civil Aviation Organisation's (ICAO) Convention deals with aeronautical telecommunications, including spectrum issues on matters related to the safety and regularity of flight. Similarly the International Maritime Organization (IMO) in its Safety of Life at Sea (SOLAS) Convention prescribes certain mandatory radiocommunications carriage requirements for certain ships dependant on their sea area of operation.

The World Trade Organization (WTO) is also important in terms of market and competition issues in radiocommunications. In 1996 the negotiating group on basic telecommunications in the WTO in the annex of telecommunications[11] developed a number of definitions and principles on the regulatory framework for basic telecommunications services, including:

> "Any procedures for the allocation and use of scarce resources, including frequencies, numbers and rights of way, will be carried out in an objective, timely, transparent and non-discriminatory manner. The current state of allocated frequency bands will be made publicly available, but detailed identification of frequencies allocated for specific government uses is not required."

2.4 The Radio Spectrum Decision & Radio Spectrum Policy Group

The Radio Spectrum Decision (RSD) is the key legal instrument in radio spectrum matters at EU level. The RSD establishes a policy and legal framework with the aim (inter alia) of:

> "optimising the use of radio spectrum and avoiding harmful interference"
>
> *Article 2(a)*

The RSD also creates a Radio Spectrum Committee (RSC) to assist the European Commission in taking formal Decisions concerning:

> "development and adoption of technical implementing measures and with a view to contributing to the formulation, preparation and implementation of Community radio spectrum policy".

[11] http://www.wto.org/english/tratop_e/serv_e/12-tel_e.htm / http://www.tiaonline.org/policy/initiatives/spectrum/index.cfm

On measures within the competence of CEPT (harmonisation of radio frequency allocation and information availability), the Commission (after consulting RSC) issues a mandate to CEPT setting out the tasks to be performed. Unlike the case of Commission mandates for harmonised standards under the R&TTE Directive (see 2.2.4), the mandated body here is named explicitly and has exclusive rights. Once it has received the advice of the RSC on the CEPT response, the Commission may determine the applicability of the measures in the Community and publish a Decision in the Official Journal of the European Union. Some Commission Decisions relevant to the scope of this project are discussed in Section 2.6.

Recital 10 of the Radio Spectrum Decision notes that the Commission may organise consultations outside the framework of the Decision. One particular example of this is an exclusive committee of high level governmental experts from each Member State and Commission representatives, the Radio Spectrum Policy Group (RSPG). The RSPG is established under Commission Decision 2002/622/EC[12] which states that:

> "The Group shall assist and advise the Commission on radio spectrum policy issues, on coordination of policy approaches and, where appropriate, on harmonised conditions with regard to the availability and efficient use of radio spectrum necessary for the establishment and functioning of the internal market."
>
> *Article 2*

The RSPG is separate and distinct from the RSC and is not intended to interfere with the operation of the RSC.

2.5 Directives

The extracts of the current Directives quoted below are considered those most relevant to the scope of the present study.

It must be pointed out that, at the moment of compiling this final report, the Commission had just adopted its proposals for a new telecom regulatory framework (the "EU Telecom Review", 13 November 2007). Although neither the Radio Spectrum Decision nor the R&TTE Directive are within the scope of the Review, these proposals[13], to be discussed by Council and the European Parliament over the course of 2008, may potentially bring significant changes to the spectrum management panorama, in that they seek to update the Framework and Authorisation Directives, as well as set up an European Electronic Communications Market Authority (EECMA).

2002/21/EC (Framework Directive)

The Framework Directive is the overarching item of the 2002 New Regulatory Framework's (NRF) legislative package. Article 8.2(d) of this Directive requires the national regulatory authorities of the Member States to promote competition by:

[12] Commission Decision 2002/622/EC of 26 July2002 establishing a Radio Spectrum Policy Group

[13] See http://ec.europa.eu/information_society/policy/ecomm/library/proposals/index_en.htm

"…encouraging the efficient use and the effective management of radio frequencies…"

Article 9 concerns "Management of radio frequencies for electronic communications services" and sets out, in particular:

9.1	Member States shall ensure the effective management of radio frequencies for electronic communication services in their territory in accordance with Article 8. They shall ensure that the allocation and assignment of such radio frequencies by national regulatory authorities are based on objective, transparent, non-discriminatory and proportionate criteria.
9.2	Member States shall promote the harmonisation of use of radio frequencies across the Community, consistent with the need to ensure effective and efficient use thereof and in accordance with the Decision No 676/2002/EC (Radio Spectrum Decision).
9.3	Member States may make provision for undertakings to transfer rights to use radio frequencies with other undertakings.
9.4	Member States shall ensure that an undertaking's intention to transfer rights to use radio frequencies is notified to the national regulatory authority responsible for spectrum assignment and that any transfer takes place in accordance with procedures specified by the national regulatory authority and is made public. National regulatory authorities shall ensure that competition is not distorted as a result of any such transaction. Where radio frequency use has been harmonised through the application of Decision No 676/2002/EC (Radio Spectrum Decision) or other Community measures, any such transfer shall not result in change of use of that radio frequency.

2002/20/EC (Authorisation Directive)

Recital (5) of this NRF Directive clarifies:

"This Directive only applies to the granting of rights to use radio frequencies where such use involves the provision of an electronic communications network or service, normally for remuneration. The self-use of radio terminal equipment, based on the non-exclusive use of specific radio frequencies by a user and not related to an economic activity, such as use of a citizen's band by radio amateurs, does not consist of the provision of an electronic communications network or service and is therefore not covered by this Directive. Such use is covered by the Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity"

Article 2.2 provides the definition of "harmful interference" – see Section 3.1 of this report. Article 5 sets out "Rights of use for radio frequencies and numbers":

5.1 Member States shall, where possible, in particular where the risk of harmful interference is negligible, not make the use of radio frequencies subject to the grant of individual rights of use but shall include the conditions for usage of such radio frequencies in the general authorisation.

5.2 Where it is necessary to grant individual rights of use for radio frequencies and numbers, Member States shall grant such rights, upon request, to any undertaking providing or using networks or services under the general authorisation, subject to the provisions of Articles 6, 7 and 11(1)(c) of this Directive and any other rules ensuring the efficient use of those resources in accordance with Directive 2002/21/EC (Framework Directive).

Without prejudice to specific criteria and procedures adopted by Member States to grant rights of use of radio frequencies to providers of radio or television broadcast content services with a view to pursuing general interest objectives in conformity with Community law, such rights of use shall be granted through open, transparent and non-discriminatory procedures.

When granting rights of use, Member States shall specify whether those rights can be transferred at the initiative of the right holder, and under which conditions, in the case of radio frequencies, in accordance with Article 9 of Directive 2002/21/EC (Framework Directive). Where Member States grant rights of use for a limited period of time, the duration shall be appropriate for the service concerned.

5.3 Decisions on rights of use shall be taken, communicated and made public as soon as possible after receipt of the complete application by the national regulatory authority, within three weeks in the case of numbers that have been allocated for specific purposes within the national numbering plan and within six weeks in the case of radio frequencies that have been allocated for specific purposes within the national frequency plan. The latter time limit shall be without prejudice to any applicable international agreements relating to the use of radio frequencies or of orbital positions.

5.4 … With regard to competitive or comparative selection procedures for radio frequencies Article 7 shall apply.

> 5.5 Member States shall not limit the number of rights of use to be granted except where this is necessary to ensure the efficient use of radio frequencies in accordance with Article 7.

Article 6 allows for conditions to be attached to the general authorisation and the rights of use for radio frequencies in accordance with Annexes A & B of the Directive. Annex A point 15 allows for:

> "…conditions to prevent electromagnetic interference between electronic communications networks and/or services in accordance with Council Directive 89/336/EEC of 3 May 1989[14] on the approximation of the laws of the Member States relating to electromagnetic compatibility."

Annex B point 3 allows:

> "Technical and operational conditions necessary for the avoidance of harmful interference… where such conditions are different from those included in the general authorisation."

1999/5/EC (R&TTE Directive)

Article 2(i) defines "harmful interference" in a manner consistent with the Authorisation Directive – see Section 2. Article 3.2 then requires that:

> "…radio equipment shall be so constructed that it effectively uses the spectrum allocated to terrestrial/ space radio communication and orbital resources so as to avoid harmful interference."

Not withstanding this requirement, there is an overriding provision in Article 7.2 which can be applied on a case-by-case basis if so required:

> "…Member States may restrict the putting into service of radio equipment only for reasons related to the effective and appropriate use of the radio spectrum, avoidance of harmful interference…"

2004/108/EC (EMC Directive)

This Directive governs the EMC of unintentional electrical and electronic radio frequency radiators, which are not governed by any other Directive. Article 2.1(e) provides a definition of "electromagnetic disturbance" as

> "…any electromagnetic phenomenon which may degrade the performance of equipment. An electromagnetic disturbance may be electromagnetic noise, an unwanted signal or a change in the propagation medium itself."

[14] This first EMC Directive was superseded by Directive 2004/108/EC of the European Parliament and of the Council of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility and repealing Directive 89/336/EEC.

Annex 1 then goes on to elaborate:

> "Equipment shall be so designed and manufactured, having regard to the state of the art, as to ensure that:
>
> (a) the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended;
>
> (b) it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.

Article 4 indicates that the Directive shall not prevent the application in any Member State of special measures concerning the putting into service or use of equipment to overcome an existing or predicted electromagnetic compatibility problem at a specific site or for safety reasons to protect public telecommunications networks or receiving or transmitting stations when used for safety purposes in well-defined spectrum situations.

As a new approach Directive, compliance with an 'EMC' harmonised standard will provide a manufacturer or supplier with a presumption of conformity with the essential requirements and allow the product to be placed on the market. Interestingly harmonised standards for various products have varying radiation limits at the same frequency to avoid disturbing radio networks and systems. And in most cases such limits would exceed the protection and compatibility criteria developed for the efficient use of spectrum and the minimisation of interference.

Other Directives

Lastly, two[15] much older Directives have similar effect to implementing measures under the Radio Spectrum Decision:

87/372/EEC (GSM Directive) on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community

91/287/EEC (DECT Directive) on the frequency band to be designated for the coordinated introduction of digital European cordless telecommunications (DECT) into the Community

[15] A third Directive of similar nature, "90/544/EEC (ERMES Directive) on the frequency bands designated for the coordinated introduction of pan-European land-based public radio paging in the Community" was repealed by Directive 2005/82/EC and substituted by Commission Decision 2005/928/EC on the harmonisation of the 169,4-169,8125 MHz frequency band in the Community.

The primary purpose of these two directives is to designate the frequency bands for the respective technologies. In the case of GSM, the band is reserved for exclusive use of cellular digital mobile communications with the exception of previously existing point-to-point links which were allowed to remain "provided they do not interfere". In the case of DECT, DECT is given priority and must be "protected". The recitals of the DECT Directive make explicit reference to the EMC Directive current at the time and the need to avoid "harmful electromagnetic interference". Neither Directive introduces definitions or interpretations of interference, harmful or otherwise.

The two Directives may, in future, be repealed[16] and replaced by implementing measures under the Radio Spectrum Decision in order to permit more flexible use of the spectrum concerned or to clarify the extent of such flexibility.

2.6 Commission Decisions

Several Commission Decisions comprising implementing measures under the Radio Spectrum Decision modify the concept of "harmful interference" as defined in the Authorisation Directive and R&TTE Directive by introducing the concept of "non-interference and non-protected basis":

> **2007/131/EC** on allowing the use of the radio spectrum for equipment using ultra-wideband (UWB) technology in a harmonised manner in the Community.
>
> **2006/804/EC** on harmonisation of the radio spectrum for radio frequency identification (RFID) devices operating in the ultra high frequency (UHF) band.
>
> **2006/771/EC** on the harmonisation of the radio spectrum for use by short-range devices (SRD).

The applicable definition in the above cases is: "non-interference and non-protected basis" means that no harmful interference may be caused to any radiocommunication service and that no claim may be made for protection of these devices against harmful interference originating from radiocommunication services.

Three other Decisions embody a similar principle but with slightly different terminology:

> **2007/98/EC** on the harmonised use of radio spectrum in the 2 GHz frequency bands for the implementation of systems providing mobile satellite services (MSS)
>
> Any other use of these bands shall not cause harmful interference to systems providing mobile satellite services and may not claim protection from harmful interference caused by systems providing mobile satellite services.

[16] The Proposal for a Directive of the European Parliament and of the Council repealing Council Directive 87/372/EEC on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community was adopted by the Commission on 25 July 2007 [Document COM(2007) 367]. A draft Commission Decision replacing the Directive has been agreed by the RSC [Document RSCOM07-04 Final].

2005/50/EC on the harmonisation of the 24 GHz range radio spectrum band for the time-limited use by automotive short-range radar equipment in the Community

'non-interference and non-protected basis' means that no harmful interference may be caused to other users of the band and that no claim may be made for protection from harmful interference received from other systems or services operating in that band;

2004/545/EC on the harmonisation of radio spectrum in the 79 GHz range for the use of automotive short-range radar equipment in the Community.

A 'non-interference and non-protected basis' shall mean that no harmful interference may be caused to other users of the band and that no claim may be made for protection from harmful interference received from other systems or services operators operating in that band.

As well as the Decision replacing the GSM Directive, other EC Decisions are currently being discussed in the RSC for finalisation in early 2008, notably on Broadband Wireless Access (BWA), Mobile Communication services on Aircraft (MCA), mobile TV and specific UWB applications. Decisions on SRD and UWB are also due to be amended.

3. Standardising Interference Definitions

3.1 Current Interference Definitions

Defining interference is not straightforward: a signal which causes problems to one technology or user may cause a disturbance of little consequence to another.

In order to understand interference, and make comparisons between different interference mitigation schemes and management techniques, it is first necessary to define what is meant by interference. There are several definitions of interference, different both on axes of severity (i.e. to what extent the interference causes a problem) and of definition (i.e. the measure of performance which is affected).

> **Harmful Interference:** Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with Radio Regulations.
>
> *Article 1 of the ITU Radio Regulations*

This is adapted in the EU context as:

> **Harmful Interference** means interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with the applicable Community or national regulations.
>
> *Article 2.2(b) of the Authorisation Directive & Article 2(i) of R&TTE Directive*

The R&TTE Directive requires that:

> … radio equipment shall be so constructed that it effectively uses the spectrum allocated to terrestrial/space radio communication and orbital resources so as to avoid harmful interference.
>
> *Article 3.2, R&TTE Directive*

Whilst avoiding use of the particular term 'harmful interference', the EMC Directive defines 'electromagnetic disturbance' and requires equipment to be designed and manufactured to ensure that:

> … the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended;
> … it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.
>
> *Annex 1, 1(a) & (b), EMC Directive*

Outside the EU regulatory context, other definitions of harmful interference exist. For example, in the ITU Tallinn Agreement, harmful interference:

> … shall be construed as any emission which causes serious degradation in the quality of the traffic of a radiocommunication service, or repeatedly disrupts or interrupts that service by exceeding the maximum permissible interference field strength specified in Annex 1 of Tallinn agreement.
>
> *ITU-R Tallinn Agreement Rec. 1049-1*

In addition to various definitions of, or which relate to harmful interference, the ITU goes on to define two further degrees of interference, 'permissible' and 'accepted'.

> **Permissible Interference:** Observed or predicted interference which complies with quantitative interference and sharing criteria contained in these Regulations or in ITU-R Recommendations or in special agreements as provided for in these Regulations.
>
> *Article 1 of the ITU Radio Regulations*

> **Accepted Interference:** Interference at a higher level than that defined as permissible interference and which has been agreed upon between two or more administrations without prejudice to other administrations.
>
> *Article 1 of the ITU Radio Regulations*

3.1.1 What Constitutes 'Harmful'?

In the foregoing definitions of interference, there are differences in how the severity with which interference affects the victim system is identified, from 'endangering the functioning of safety services' through 'seriously degrading or interrupting' a service, to 'operating as intended'. Furthermore, whilst interference may cause a serious effect on one system, other systems operating in the face of the same interference may continue to operate unaffected. This is evidenced to some extent in the singling out of 'radionavigation and other safety services' for special treatment.

Thus, a single, universal definition of interference is difficult to achieve. For example, the ITU (and EU) definition of harmful interference itself has a twofold approach in that it considers interference to 'radionavigation or other safety services' separately from that to other services. Further, the services which are covered by the term 'safety services' are not specifically identified and thus, whilst some services (such as maritime distress frequencies) are clearly 'safety of life' related, exactly which services are subject to the differentiated level of protection is also somewhat unclear. This is further complicated by the fact that services which might not normally be categorised as 'safety of life' for example the PMR system used by a taxi company, may become such if a taxi carrying a critically ill patient to hospital needs to communicate. Or, for example, the telemetry from a water pumping station: normally this would provide every day operational information but if there were damage to the water system which might endanger human life (or property), reception of telemetry may become a life and death matter.

3.1.2 "Electromagnetic Disturbance" and "Harmful Interference"

The first project workshop[17] in the framework of the present study and the associated on-line questionnaire to stakeholders explored the potential overlap between the concept of 'electromagnetic disturbance' in the EMC directive and 'harmful interference' in the R&TTE directive. There is a generally held view that electromagnetic disturbance concerns emissions from what is defined for the purposes of regulation in the USA as an 'unintentional radiator[18]' or 'incidental radiator[19]' whereas harmful interference concerns emissions from an 'intentional radiator[20]'. This view is held despite harmful interference being a concept applicable to all classes of radiator in the US regulatory framework.

The question:

> *"How do you relate the avoidance of harmful interference under Article 3.2 of the R&TTE Directive to the requirement under Article 3.1(b) for electromagnetic disturbance not to 'exceed the level above which radio... equipment cannot operate as intended'?"*

the project online questionnaire elicited the following responses which illustrate the perception in the EU:

> "Article 3.2 is a spectrum requirement for radio equipment concerning spurious emissions etc along with the intended emission. EMC requirements are concerned with unintended emissions" *[Supplier/Service Provider]*

> "3.1 is referred to the EMC (same location) and 3.2 in cases of spurious signal interfering in a system far from the transmitting location" *[Regulator]*

> "Art. 3(2) deals with far-field propagation situations related to antenna port, while art 3(1b) deals with near-field and short distance mechanisms like exposure of equipment cabinet to strong electromagnetic fields and power supply and signal port immunity." *[Regulator]*

One regulator went so far as to comment:

> "Complex legal issues cannot be answered generally but must be assessed on a case-by-case basis."

[17] Brussels, 3 May 2007

[18] FCC Part 15.3(z) Unintentional radiator. A device that intentionally generates radio frequency energy for use within the device, or that sends radio frequency signals by conduction to associated equipment via connecting wiring, but which is not intended to emit RF energy by radiation or induction.

[19] FCC Part 15.3(n) Incidental radiator. A device that generates radio frequency energy during the course of its operation although the device is not intentionally designed to generate or emit radio frequency energy. Examples of incidental radiators are dc motors, mechanical light switches, etc.

[20] FCC Part 15.3(o) Intentional radiator. A device that intentionally generates and emits radio frequency energy by radiation or induction.

It is certainly the case that the harmonised standards concerning articles 3.1(b) and 3.2 of the R&TTE directive have been prepared with the model outlined above in mind. However, the distinction is not supported in the European regulatory texts.

This is a matter which must be resolved for an interference-based approach to spectrum management. The obvious choice is between aligning with the current widely held view in the EU which differs in detail from the US or to align more fully with the US interpretation. The consequences of doing nothing leave the basis for enforcement (or non-enforcement) action open to challenge and the denial of "harmful interference" from electrical equipment or installations in general. It may be desirable or practicable to address only the first of these in the short term because of the more extensive changes to EU legislation necessary to achieve the latter.

Alignment with the currently held view in the EU is not the preferred option because it would prevent a harmonised approach to incidents of harmful interference. Data provided by the Finnish NRA following the first project workshop suggest some 20% of interference complaints arise from electrical (non-radio) equipment. It is unsatisfactory that none of these can be classified as harmful interference and the corresponding sanctions applied.

The recommendations for implementation which are set out in this report therefore reinforce the view that **harmful interference is a subset of electromagnetic disturbance** for which particular enforcement measures may be prescribed. The consequential amendments to the R&TTE Directive would then permit, for example, the pursuit of interference from power line communication terminal equipment to be treated as harmful interference.

3.1.3 Non-Interference and Non-Protected Spectrum Use

The term "non-interference and non-protected use" occurs in various Commission Decisions (see 2.6). As for non-interference, the following formulations occur:

- "no harmful interference may be caused to any radiocommunication service";
- "no harmful interference may be caused to other users of the band"; and
- (in relation to mobile satellite services in the 2GHz band) "any other use of these bands shall not cause harmful interference to systems providing mobile satellite services".

Given the over-riding prohibition on all radio equipment that it "shall be so constructed that it effectively uses the spectrum allocated to terrestrial/space radio communication and orbital resources so as to avoid harmful interference"[21] these elaborations are at best tautological and, in the second and third cases, unhelpful in their misleading implication that harmful interference other than to users of the band would be in order.

[21] R&TTE Directive Article 3.2

In terms of non-protected, we have:

- no claim may be made for protection of these devices against harmful interference originating from radiocommunication services;
- no claim may be made for protection from harmful interference received from other systems or services operating in that band; and
- (in relation to mobile satellite services in the 2GHz band) no claim for protection from harmful interference caused by systems providing mobile satellite services.

The meanings here are materially different and modify the protection inherent in the essential requirement of the R&TTE Directive quoted above. Harmful interference as defined in the R&TTE Directive and the Authorisation Directive has meaning only in relation to certain specific services (radionavigation etc) and so may not be what is intended here. Whatever is intended, there is a material difference between whether protection is denied across the spectrum or simply in the band or for the class of device in question. Furthermore, it needs to be clarified whether a qualification of the nature "operating in accordance with the applicable Community or national regulations", as in the harmful interference definition itself, should also appear in the statement of the systems, services or whatever from which protection is not available. Without such, there would be doubt about whether there is redress against illegal equipment causing interference.

Establishing the clear intent in the above is important since the concepts make a material difference to the way that "harmful interference" is interpreted for authorisation and enforcement purposes and this, in turn, affects spectrum planning decisions.

3.2 The Impact of Interference

One of the key impacts of interference, whatever the actual level, is the effect it has on the victim system. Moreover, given that the same absolute level of interference may have very different relative effects on the victim systems concerned, one way in which interference could be consistently defined is in terms of the effect it has on the victim system – and to a large extent, this is what the existing definition tries to do.

However, the effect on the victim system could be mitigated through modifications to the system itself. For example, if better receive filters are installed on the victim system, the effect of any interference may be reduced and thus the same interference may have a less severe effect on the modified victim system.

Even when interference is not present, successful communications only exist when radio signals are sufficiently strong relative to the background noise levels, to be able to be decoded. Interference can have the effect of raising the level of background noise above these ambient levels. Such a raising of the noise levels may be caused by radio interference from other transmitters or, in fact, by any electrical device. Most radio systems (with the possible exception of ultra-weak signal services such as radio astronomy) are designed to work in situations where interference is somewhat above the background noise levels and indeed, in most urban or suburban environments the noise level is already orders of magnitude greater than natural background levels due to noise generated by electrical equipment.

We could therefore define interference in one of two ways:

- **Absolute:** Where the level of interference caused can be measured in comparison to some pre-defined constant.
- **Relative:** Where the interference is measured by means of the impact it has on a victim system.

The pros and cons of each of these methods are highlighted in the following table:

	Absolute	Relative
Pros	• Simple to measure. • Easy to factor into system designs.	• Relates interference directly to the impact it causes on victim systems.
Cons	• The same level of interference may cause different levels of 'harm' to different victim system.	• Different levels of interference may not be easily comparable. • Changes in technology may alter the effect on the victim system.

In considering the implications for interference management techniques, either or both of these definitions may be applicable. Many of the existing interference definitions appear to weigh more heavily towards a relative definition. Certainly, the concept of harmful interference is clearly a relative measure as the harm caused to a system will vary depending upon the parameters of the system in question. Since the systems operating in a highly interference limited environment will be designed specifically to tolerate these levels, the level of interference which will cause harm will be much greater than the level of interference which will cause harm to weak signal services such as radio astronomy or amateur radio.

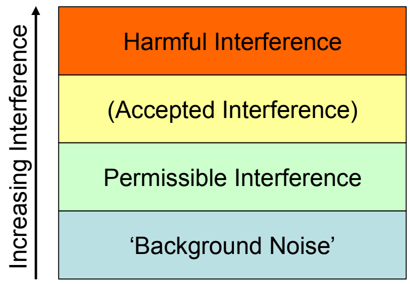
To make meaningful comparisons between different interference scenarios, it is essential to define interference in a consistent way. Furthermore, many of the existing definitions are at the upper extremes of interference, in that they usually refer to levels of interference where the victim system is unable to continue to operate correctly, whereas lower levels of interference may still cause systems to operate sub-optimally.

Most commercial mobile telecommunications networks, for example, are typically specified to achieve a certain grade of service. As the greatest congestion usually occurs at the air interface, this is the most critical part of the system. Thus the spectrum dependent element of the system limits overall system performance. Even small increases in interference, insufficient to be termed 'harmful', can cause sufficient degradation in the air interface to make the achievement of the designed grade of service impossible (or cause the necessity for significant additional investment in network infrastructure to overcome the effect). In the same situation, some levels of interference may be acceptable in that they can be designed around or are insufficient to upset the operation of the system. For wideband systems, for example, even high levels of narrowband interference may make little or no impact on overall system performance (and vice versa wideband impacting on narrowband).

We thus need definitions that are not just at the extremes but take account of the wide range of interference scenarios both in terms of absolute and relative interference. It also seems rather arbitrary to single out safety services for special treatment – surely all radio users should be afforded the same effective level of interference protection. A mobile telecommunications network can be considered to carry safety-of-life traffic on a daily basis in the form of carrying calls to the emergency services.

If we take 'harmful' interference to be the upper relative extreme we might therefore define relative interference in the following ways:

- **Harmful:** levels of interference which significantly degrade, obstruct or interrupt a radiocommunication service;
- **Accepted:** levels of interference which substantially degrade, obstruct or interrupt a radiocommunication service but which are agreed between neighbouring[22] users;



- **Permissible:** levels of interference which may reduce performance, but do not substantially degrade, obstruct or interrupt a radiocommunication service;
- **Background Noise:** levels of interference which are in line with the expectations set in ITU-R P.372 (Radio Noise).

Of course there are many distinctions between levels of interference that could be made. We could use three or five levels instead of four. What is useful, however is to consider the two key levels: 'harmful' and 'permissible'. Harmful follows the traditional concept of 'significant harm' whereas 'permissible' is, in effect, the maximum level of interference that a system may expect to suffer on a regular basis. Accepted interference is a level that is reached by agreement between administrations and as such the difference between the upper level of permissible interference and the lower level of harmful interference may be, in effect, zero in that there is no level considered as accepted interference.

3.2.1 A Technical Approach to Harmful Interference

The various definitions of 'harmful' interference, despite having internal inconsistencies and ambiguities, do have some common ground on which we can draw. Firstly there is the concept that harmful interference causes a significant degree of degradation in the affected services. Clearly different levels of interference degrade the operation of a service to different degrees. However all the existing definitions of harmful interference concur that the interference being described makes a severe impact on the victim system. Furthermore, there is the concept (for non safety-of-life or radio navigation services) that such interference is not just a one-off, but is repetitive.

[22] Neighbouring refers to those users either geographically of spectrographically close.

For any service, almost without exception, there will be naturally occurring phenomena which cause an interruption to the service. Such phenomena include ambient radio background noise levels and propagation anomalies caused by solar, weather or physical conditions. These interruptions are part of the planning criteria of any service, in that most services are planned to be available for a specified percentage of time, probability or area over which the radio service will function as intended. Depending on the required quality of service, these percentages can range from as low as 50% to over 99.999%. Thus there is an inherent, 'natural' level of interruption to a service which, by the definition of the system operating parameters, is not harmful in that it is planned for in the system design. This is true of any radio system, regardless of frequency band, range or coverage; no system can ever guarantee 100% reliability where radio signals are concerned, even with double or triple redundant coverage.

Radio system planners rely on the fact that the background noise level (which includes both natural and man-made elements) has been well defined[23] and thus planning can take accurate account of the occurrence of certain levels of this noise. It is clearly important, in this situation, that the expected levels of background noise are well defined for such parameters to be used. There is a project currently under way in the ITU to revise the charts which are used to define the level of background noise as the existing figures have been in use for over 30 years. Over this time period, there has been an enormous rise in the amount of electrical equipment in use which would have the effect of raising the ambient noise levels, whereas over the same period, tighter controls on the emission levels that such devices can generate have been put in place. The review of the ambient noise levels was not completed during the timescale of this project. However comments from those undertaking the review suggest that the difference in man-made levels of noise from the measurements of 30 years ago is not overly significant. This is not to say that the level of man-made interference is insignificant, indeed it is one of the major sources of radio noise in urban and suburban areas, especially at low frequencies. Nor does it imply that, so far, the effect of the reductions in emissions brought about by the application of EMC and other restrictions are offsetting those caused by the increase in the use of electrical equipment.

In addition to these background noise levels, any radio system will also experience incidental interference from other radio services in operation on nearby frequencies. Incidental interference in this sense is interference which is a by-product of radio usage through the emission of wideband noise and spurious signals that all radio transmitters produce. Such incidental interference is not the in-band or out-of-band interference caused by transmitters operating on neighbouring frequencies which are much more significant. The incidental interference will appear as an overall increase in background noise levels and this increase has been shown[24] to vary from just a few to tens of dBs.

Propagation and atmospheric anomalies are less predictable, and are more pertinent to long rather than short-range services. However the extent to which any particular anomaly will impact reception in any particular frequency band is well established and as such is taken into account when planning services. Even short-range links will be affected by nearby lightning strikes for example.

[23] In ITU-R P.372

[24] http://www.ofcom.org.uk/research/technology/overview/state_use/aims2/aims2_1.pdf

All the above issues are known and documented and have the potential to interrupt a service; however they are accepted as an everyday consequence of using the radio spectrum. Any increase in interruption to service above that caused by those accepted phenomena will cause some degree of degradation of the quality of service being provided. The question of a definition of interference therefore becomes:

> ***To what extent should the impact of other radio users raise the occurrence of interruptions or degradations beyond 'natural' levels before such interruptions or degradations are classified as 'harmful'?***

In considering the case of interference caused to direct-to-home satellite reception by MVDDS services operating in the same frequency band[25], the FCC concluded that:

> "an increase of ten percent over current [satellite reception] unavailability is the appropriate starting point for our analysis".

It further noted that, the extent to which interference was likely to be noticed would vary as the number of people watching the satellite service changed. It also noted that the causes of interference (which in the case of DTH-TV are largely weather related) were seasonal and as such care needed to be taken in defining a time period for the measurement of effects so as not to skew the results. A 10 percent increase was also seen as the point at which the effects of interference would be sufficiently significant to be measurable and not just be a possible outcome of everyday variations.

One might also consider the example of 'nano power' FM transmitters used for relaying the output of mp3 players and other audio devices to nearby FM receivers. In a static environment (e.g. in the home) it is highly unlikely that the user would select a frequency which caused interference to licensed radio services in the band, not least because the relative powers of the services means that it is more likely that the licensed service would interfere with the nano-transmitter than vice versa, and also because it is quite possible that the user would wish to be able to listen to the licensed service in addition to the output of their music player. In a mobile environment, the localised interference caused by nano-transmitters in close proximity to other users is fleeting as the users pass. Thus the increase in outages caused by such a transmitter may be significantly below the theoretical impact which might otherwise be calculated if the 'full impact' of the transmitter were assumed.

Thus whilst the concept of defining harmful interference as an increase in outages or degradations above those caused naturally seems relatively straightforward, any predictions based on such a definition would need to take account of more than just technical considerations. Nonetheless, providing a precise definition of harmful interference in this way allows the effects of such interference to be clearly measured in practice – something that cannot be said of existing definitions.

[25] http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-00-418A1.pdf

Interference, by its nature, will affect one radio technology differently from another. Some systems are designed to operate in a high interference environment whereas others require very low interference environments. The existing ITU and EU definitions are relative, in that they define only the impact on a specific system. The definition adopted in the Tallinn agreement is absolute in that it specifies a certain interfering signal level (or field strength). Given the role that technology has to play in determining the impact of any given level of interference, any definition of interference needs to encompass both these elements to give the maximum degree of certainty to all systems and services and to try and reduce any legal ambiguity that might otherwise arise.

Given that the 'quality' of most radio services is currently defined in terms of probability (e.g. the % likelihood of reception) a definition of interference which is also based on probability seems highly appropriate. Such a probability based definition could include both relative and absolute measures and thus be applied consistently across different technologies.

An example of such a definition for harmful interference might be:

> *Interference which (over a given period of time or area) raises r.m.s. noise levels by 1.76 dB or increases system outages by 50%, whichever is the most significant.*

A 1.76 dB increase in noise represents a 50% increase on background noise power[26]. In some systems such an increase may not prove particularly significant, whereas in others it might prove disastrous. There is also an issue with measuring noise levels. Whilst accurate measurements can be taken, there needs to be a significant increase before statistical inaccuracies in noise measurement allow changes to be verified, as such an increase of at least 1dB is probably necessary in order to be certain that any measured difference is real.

An increase in system outages by 50% would take, for example, a system with a planned outage of 1% to an outage of 1.5%. The critical factor in this instance would be that the increased level of outages would be over the same time period as the planned period. So if the system was planned to have a 1% likelihood of outage over a year, then the impact of the interference should be measured over the same period. Clearly any interference which caused the outage likelihood to be breached in a short period of time would automatically classify as harmful (e.g. a 1% likelihood represents 87 hours per year – thus a continuous outage of 44 hours would automatically breach the definition whenever it took place, assuming it was not caused by predictable causes).

For short-range systems such as WiFi, whilst the increase in noise may have no effect, it is still arguable that a 50% increase in outages would be harmful, whatever the baseline level of interference or noise. To get a 50% increase in outages might represent a 20 dB increase in noise in this circumstance; however the definition still holds.

[26] Note that this does not necessarily imply or relate to a 50% increase in outages. However some systems are sensitive to noise increases, others will be interrupted to the point of failure and thus the dual definition attempts to address both these situations.

Whether or not a 50% increase in outages or a 1.76 dB rise in noise is a reasonable benchmark to represent a level constituting 'harmful' and whether such a definition could reasonably apply depends partly on whether these are reasonable metrics but very critically on whether or not the systems impacted have accurately defined their expected outages and/or the level of noise taken into account in system planning. Such information may be available in some compatibility studies, or in the case of some commercial systems in their contracted availability. However it could be a particularly onerous task to retrospectively calculate outage or expected system noise parameters where such do not exist.

3.2.2 Lesser Degrees of Interference

Whilst there is a need to arrive at a standard definition for harmful interference, if interference has reached harmful levels there is already a significant degradation in service. There are clearly instances where interference levels below those which might be regarded as harmful are nonetheless an issue for radio users and there needs to be a consistent unambiguous definition of these levels too.

The concept of permissible interference is a useful concept as the existing definition suggests that this is a level of interference which users should be able to deal with. Based on the US discussions presented above, it would seem that an increase in outages of 10% would perhaps be a reasonable representation of permissible interference. This is supported by the concept that this is the minimum level at which the increase might be reasonably accorded to interference instead of to naturally occurring factors.

In what is arguably one of the services most sensitive to interference, the Committee on Radio Astronomy Frequencies has defined the levels of harmful interference[27] for the radio astronomy service. Based on these criteria and the adopted integration time of 2000 seconds:

> "interference levels are considered to be harmful to the Radio Astronomy Service when the r.m.s.fluctuations of the system noise increase at the receiver output by 10% due to the presence of interference."

[27] http://www.craf.eu/harmdef.htm

A 10% increase in system noise represents only a 0.42 dB rise in r.m.s. noise levels, significantly below the suggested 1.76 dB rise suggested above. However the system noise levels at which radio astronomy systems are operating are significantly lower than those employed in virtually any other radio system. Also note that the definition measures noise at the receiver output and not its input – this is significant when long integration time coherent receivers are used which are much more sensitive than typical receivers. In most systems, an increase in noise of 0.42 dB would be virtually unnoticeable. It is only because radio astronomy systems are so sensitive that such a change is measurable or, for that matter, significant. It is clear, therefore that for the radio astronomy service a 1.76 dB rise in noise may prove unacceptable. However the proposed alternative '50% increase in outage' would presumably be highly acceptable to them, in that it is assumed that planned system outages would be very small and as such a small increase would still represent a very tiny change in outages.

3.2.3 A Market Basis for Determining Harmful Interference

Considering:

- the ITU framework for the interference ranges;
- the conflicting levels at which interference might be considered harmful;
- the desire for an absolute definition of harmful interference; and
- a move, more generally, to consider the use of market-based mechanisms in spectrum management;

the possibility presents itself of allowing market forces to determine the appropriate level of interference, and in particular for agreeing what represents harmful interference to a service.

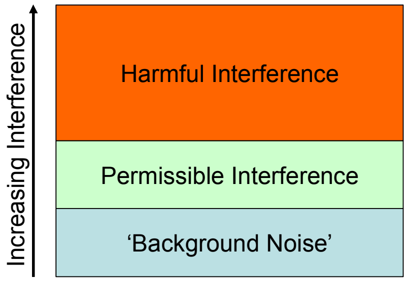
From the above discussion, it is clear that a '10%' increase in noise or outages is the minimum which could be reasonably measured and that levels below this are, even for radio astronomy, not normally considered harmful. As such, we could define this as the level of permissible interference. What therefore represents harmful interference would be an increase above this permissible level. It is feasible, therefore, that individual users could define their own level of harmful interference, both in terms of that which they are prepared to accept, and that which they cause to neighbouring users. Thus, the range of acceptable interference, which is already subject to agreement between spectrum users (albeit currently by administrations and not the users themselves), becomes a negotiable 'buffer zone' between permissible levels and those which users consider harmful.

In the absence of any negotiation or discussion between users, the default position would be that there is no acceptable interference zone and that anything that exceeds the level of permissible interference is classed as harmful. This is unlikely to be achievable by many radio users and hence there is an immediate incentive to reach a negotiated solution.

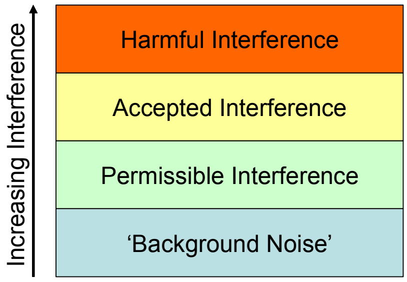
The key difference between this approach and the existing approach is that instead of system parameters being determined *a priori* through compatibility studies, users would have the flexibility to define their own system parameters both in terms of their susceptibility to interference and the amount of interference they generate, and to trade off the system parameters against the commercial realities of negotiating a accepted interference solution with neighbouring spectrum users. The extent to which neighbours would have to be consulted would depend on the spectral and potentially the geographical reach of out-of-band emissions from a proposed technology. It is possible, of course, that the use of guard bands or strong filtering within a user's in-band assignment might reduce any out-of-band emission to permissible levels such that no negotiation is necessary.

Thus the situation would be as follows:

- Interference would be defined relative to the (currently under revision) ITU definitions of the expected levels of background noise present in different (i.e. rural, urban) areas.



- Users would expect to deal with a level of permissible interference that is x% or y dB above this. An x of 10% and a y of 0.42 dB seem to be a good starting position. They must also not generate in excess of this to any neighbouring spectrum users
- In the absence of any negotiations, this is the default position which applies to all radio users.
- Neighbouring users (any users impacted by or likely to suffer from interference from emissions) are allowed to negotiate a relaxation of this position and introduce a region of accepted interference.



Negotiations could include technical and commercial aspects. Clearly there needs to be sufficient liberalisation in spectrum authorisation to allow change of use in spectrum for such negotiations to take place. In essence, such a procedure represents one of the ways in which usage rights for spectrum can be defined. Other definitions may also be appropriate, and the use of other techniques such as masks and other usage rights may be necessary in addition to a harmful interference based solution. However a method of this kind offers a clear safeguard to spectrum users that they will not, unless agreed, expect to suffer harmful interference, whilst ensuring that, even without negotiation, spectrum users have the flexibility to take decisions on system design trade-offs.

Most attempts to define the rights of spectrum users are centred on a series of technical parameters which link directly to either the operation of a transmitter or a receiver. Examples of this include spectrum masks and reception based power flux density measurements. The definition of usage rights is an essential element of the introduction of spectrum trading and many administrations are working to produce a set of applicable terms and descriptions. Regardless of how such rights are defined, contraventions of the terms set out will have one main impact: interference. As such, if those rights were defined in terms of interference and one's expectations of it, the necessity for producing complex spectrum masks is negated.

If (and only if) a level of background noise for any given site and frequency can be arrived at (and this may not necessarily be the level measured today), and an agreement of the level of 'permissible' interference above this can be defined, then it becomes possible to use these definitions to define spectrum rights. A user should not expect levels of interference in excess of the defined permissible level, nor should they cause interference to adjacent (geographically or spectrographically) users which would cause their permissible interference level to be breached (noting that their level may be different, especially if the service is different, although the level of background noise should be roughly similar).

In this situation, adjacent users (or indeed any user affected by a change) would be free to negotiate and trade the amounts of interference they caused, and to agree a level of accepted interference amongst themselves. The results of any such agreements would need to be recorded in their licence or in a central database so that if any trading were to take place, those who wished to procure a piece of spectrum would understand what the interference landscape would comprise. If no agreement could be reached between operators, the permissible level would stand as the reference.

3.3 Terminology and Implementation Inconsistencies

As discussed earlier, various different documents provide varying descriptions of interference which, whilst in some ways are compatible with each other, nonetheless are at variance and do not provide a single definition of interference. Moreover, within the definitions themselves (see 3.1) there are terms which are open to interpretation and ambiguity. It is very clear, therefore, that a series of standardised definitions of interference are required if any comparison between interference situations is to be made.

The Commission's own notes on radio spectrum policy[28] observe that in the context of the Authorisation Directive "...a common definition and applicability of the concept of 'harmful interference' and the way it affects acquired spectrum rights in the Community, would be particularly helpful."

The definition used in the EU has its origins in the ITU and is very similar to definitions found elsewhere, including the US. The definition can be set out in a short table which illustrates its elements and facilitates identification of some of its difficulties.

[28] The relevance of the electronic communications framework to spectrum http://ec.europa.eu/information_society/policy/radio_spectrum/general_overview/links_framework/index_en.htm

HARMFUL INTERFERENCE:	
… potential effect…	***…"victim"…***
endangers the functioning of	radionavigation service or of other safety services
otherwise seriously degrades, obstructs or repeatedly interrupts	a radiocommunication service operating in accordance with the applicable Community or national regulations

The main difficulties with this formulation are:

- the terms in the "potential effects" column cannot be objectively determined – is "endanger the functioning of" more or less serious than an effect that "seriously degrades"?
- a definition of "radionavigation service" can be found in the ITU regulations but what exactly are "other safety services". ITU Recommendation ITU-R SM.1535[29] states "Safety services are radiocommunication services used for safeguarding human life and property" and gives a list of relevant frequency bands in Annex 4 but this is not definitive or exhaustive. There is no elaboration of the matter in EU directives where harmful interference is itself defined.
- is a "service" as used here only an electronic communication service as defined in the Framework Directive or only one of the services explicitly listed by the ITU or does it mean radiocommunication in general.
- Why are radionavigation services singled out for special treatment? If such services are related to safety of life (as is suggested by the wording of the definition itself) then they are covered by the safety of life clause, otherwise there seems no specific reason to treat them differently.
- What constitutes a 'safety of life' service? Such a definition is highly dynamic depending on the usage of a service at a particular time.
- What is meant by 'endangers the functioning of…'? And indeed endangering the functioning implies that the functioning is not actually affected, just in peril.
- What is meant by 'seriously degrades, obstructs, or repeatedly interrupts'? Is twice 'repeatedly' or just two random examples of an interruption? Nonetheless, this phrase plus 'endangering the function…' have been used in a legal context and have proved sufficiently robust for decisions to be taken.
- Why is the definition in the Tallinn agreement so different from the others? Specifically:
  - What is meant by 'serious degradation in the quality of the traffic'?
  - Why is an absolute measure (maximum permissible interference field strength specified in Annex 1) given whereas in other definitions the measure is relative (e.g. it is based on the amount of 'damage' caused)?

[29] RECOMMENDATION ITU-R SM.1535 The protection of safety services from unwanted emissions (Question ITU-R 211/1)

The Authorisation directive applies only to electronic communication networks and services and uses the definition (i) to encourage member states not to make the use of radio frequencies subject to individual rights where the risk of harmful interference is negligible (thus encouraging a lighter touch regulatory regime); and (ii) permits the imposition (where individual rights are assigned) of technical and operational conditions necessary for the avoidance of harmful interference. The R&TTE Directive uses the definition only in the context of radio equipment and requires all such equipment to use spectrum in such a way as to avoid harmful interference.

There is no 'hook' in the EU regulatory framework which applies the concept of harmful interference to any other sources of disturbance even when such disturbance is identical in its effect of disrupting a radio service. This seems to be at variance with, for example, the USA where there is a general prohibition under Part 15 of the FCC Rules on harmful interference (similarly defined) when any electrical/electronic equipment is put into operation. This is in addition to any specific emission limits that may apply.

In the EU, this general protection is secured under the protection requirements of the EMC Directive which does not make any use of the expression 'harmful interference'. The definition of protection requirements in the EMC Directive could be interpreted to mean that "electromagnetic disturbances" to radio services are those that cause harmful interference but there is no link to specific putting-into-service or enforcement provisions concerning harmful interference in other legal measures.

Although the EMC Directive does not apply directly to radio equipment, the identical protection requirement is called up in the R&TTE Directive. Section 3.1.2 above further explored the 'electromagnetic disturbance' and 'harmful interference' concepts.

Whilst many of these issues associated with the current definition of harmful interference might be dealt with on a pragmatic case-by-case basis, there is still a strong need to produce a regularised and consistently applicable framework for dealing with different degrees of interference, both absolute and relative.

There is perhaps also a balance to be struck here between keeping a definition which has readily identifiable links to international nomenclature and something that is more strongly linked to the terminology of the Framework and other EU Directives with the potential for a less ambiguous and more objective interpretation.

3.3.1 Standard Specific Reference Levels

There exists a generic EMC standard based roughly on the IT product standard. However there are also product standards which allow for EMC levels far in excess of the generic level - railway engines and low voltage lighting are two such examples. There are also various planning criteria for radio services which in effect set the 'I' (interference) of the carrier to interference, 'C/I or C/(I+N)' ratio and thus also represent an attempt at defining the expected interference reference level. In addition, the ITU issues a series of planning criteria and emission levels and most ETSI standards also dictate the permissible levels of spurious emissions.

All these references potentially imply different values for the permitted technical emission levels from devices that radiate (whether intentionally or incidentally). Many also use different measurement techniques (e.g. quasi-peak or r.m.s.) and different measurement bandwidths meaning that the levels to which they refer are not easily comparable, nor, in many cases, do they represent the same level. Some references cover a limited range of frequencies, some wider; often the highest frequency at which such limits apply varies significantly.

Whilst setting emission levels may take into account the likely density of services of any given type, these are normally assumptions taken when developing the standards and may not be borne out in reality once the equipment or service is operating. Thus the degree to which any of these standards actually controls emissions from any given technology will vary (even if the assumptions on roll-out were relatively accurate).

Such a situation is clearly not non-discriminatory or necessarily proportional (and if the measurement is complex it may not be transparent either). Whilst there may be certain circumstances where derogation from a normalised emission standard is appropriate, in the majority of instances a normalised emission standard sets a level playing field for all concerned and ensures a consistent interference landscape for radio users.

3.4 Recommendations for Implementation

3.4.1 Harmful Interference – A European Definition

The degree of control desirable for effective and appropriate use of the radio spectrum reflects nuances finer than any revised universal definition might provide. For example, it might be desirable to control emissions where none of the specific service ameliorations cited in the existing or any revised harmful interference definition is present or to permit systematic degradation of service under certain, pre-agreed, conditions. The “harmful interference” definition in its existing form does have significant attraction:

- it is recognisable and familiar in the context of ITU activities and the use of similar definitions in other regulatory regimes, notably that of the FCC;
- it establishes a backstop for ultimate enforcement purposes notwithstanding any strict technical compliance with a quantitative limit; and
- it is useful as a vehicle for enforcement measures that are not accessible for “electromagnetic disturbance” in general.

However, in summary the study has pointed to:

- a lack of precision in the definition of harmful interference as a quantitative “backstop” for spectrum planning purposes;
- limited usefulness in setting bounds for emissions;

- confusion in both the industry and amongst regulators on the partition of phenomena between “electromagnetic disturbance” and harmful interference;

- inconsistencies in the way in which emissions levels are set;

- an inability under current instruments to classify any kind of disturbance from fixed network infrastructure or other equipment not using radio waves as the means of communication as “harmful interference” however serious the disturbance they might cause in whatever circumstances;

- lack of legal and technical basis for excluding “harmful interference” from “electromagnetic disturbance” as defined in the R&TTE and EMC Directives respectively;

- the possibility of using interference definitions as a method of defining the rights of spectrum users in a liberalised environment.

An alternative definition of “harmful interference” may eliminate or reduce some of these difficulties. However, the study suggests that a single universal definition of harmful interference suitable for all applications and technologies is unlikely to be realisable. Taking into account the uncertainty presented by the current definition, but remaining within a recognisable framework, a revised EU definition could be considered. Such a definition would need to tackle the current ambiguities but maintain current protection.

Recommendation 3.1: The following revised definition of harmful interference should be adopted in all appropriate Community texts:

Harmful Interference means interference which degrades or interrupts radiocommunication to an extent beyond that which would reasonably be expected when operating in accordance with the applicable Community or national regulations

The benefits of this revised definition include:

- the removal of any special treatment for safety of life or radionavigation;
- the removal of the term ‘service’;
- the removal of ‘obstructs’ and ‘endangers’;
- the addition of an expectation of some interruption or degradation;
- the addition of the concept of reasonableness.

While this recommendation has come too late in the Commission's internal preparatory process for adopting its Telecom Review proposals, the Council and the European Parliament could possibly consider this amended definition of harmful interference during their scrutiny of the draft legislation. It should likewise be considered in the pending review of the R&TTE Directive in 2008.

The effect and implications of the above changes are discussed in the following text.

Special Treatment of Safety of Life and Radionavigation

The term 'safety of life', whilst alluding to certain frequencies as indicated in the ITU Radio Regulations is not an all encompassing or dynamic definition. If a mobile network is used in an emergency situation then it may be carrying safety of life information, but may not enjoy any different level of protection from harmful interference.

The removal of these two terms from the definition presents a level playing field for all radiocommunication users and ensuring equal protection for any service, especially those which may carry safety of life traffic but which are not defined as such. As the term 'radiocommunication' encompasses radionavigation there is no need for a separate reference for this.

This change does not imply that these services would suffer a lower level of protection than they currently enjoy, as the proposed revised definition includes a recognition that each service will have associated with it an expected level of interruption or degradation. For radionavigation or other 'existing' safety of life services, the expectation may be for a very low level of interruptions and this expectation is carried forward and, indeed, emphasised in the proposed revision. Nor it is intended that every service should enjoy the same level of protection – instead each service is provided with the level of protection that compatibility studies or empirical evidence indicates is reasonable.

Removal of the term 'Service'

The ITU and EC definitions of service differ in that the ITU relates this to radiocommunication services whereas the EU definition of 'service' is generally recognised as relating to electronic networks. Thus there is potential for confusion to arise over the intention of the term. Its removal does not materially impact the definition (indeed it could be removed from the existing EU definition with no impact) since the terms 'radiocommunications' and 'radiocommunication service' are virtually identical. In one, radiocommunication is used as an adjective to describe the type of service being referred to, in the other it becomes the noun itself.

It could also be argued that in considering effects to 'radiocommunications' instead of 'radiocommunication services' the essence of what is being considered is more in line with the nature of what is being protected. Protecting a service implies a mechanical process in which any amelioration is caused to a system; protecting radiocommunications implies that it is the content of the transmissions or the purpose for which the system is being put that is being considered.

These are subtle nuances; however the removal of the term service does add needed clarification over the implication of the term.

Removal of the terms 'Obstructs' and 'Endangers'

Both the terms 'obstruct' and 'endanger' refer to situations in which something is in potential danger or peril, rather than one in which there is any actual impact. In essence, these are an *ex ante* terms used to prevent users taking actions which might affect others. Taken at face value, however, if a service is endangered, it may never be affected and whilst an action may have had the potential to cause interference, none may have occurred. Such a term refers more to the future potential of degradation or interruption rather than any event taking place. Thus endangering a service does not imply that any interference has actually taken place, only that there is a possibility that it might do.

Likewise an obstruction, unless total (in which case it would surely cause an interruption), is usually something which can be worked around and, unless the path happens upon the obstruction, may also not cause any effect. Alternatively an obstruction may be considered as something which impedes progress. However, such an impediment is the cause of a change to the service, not the change itself and as such the impact would either be to degrade or to interrupt the service.

Looking, therefore, at the issues of obstructions and endangerment, there seems no need to specifically include them in the definition – they are superfluous and the result of their presence is adequately covered by the terms degrade and interrupt.

The addition of an expectation of interruption or degradation

All radiocommunication is subject to natural phenomena which will cause interruption or degradation and this is taken account of when planning a service and is accepted by radio users. Harmful interference should therefore refer only to problems which occur in excess of this natural and expected level of interruption or degradation.

This addition is important in recognising the rights of individual and separate users. Each user, service, technology or use will have an expectation of the level of interruptions or degradations that they would encounter when using the radio spectrum. Such levels will vary between users and uses, and may even differ between users of the same technology if the use to which that technology is being put differs. This expectation of a certain level of service is at the core of the revised definition as, together with the concept of reasonableness, it establishes the point from which harmful interference is measured. The historical definition does not have such a clear reference point, and it could be argued that natural interruptions would, under the previous terms, be classed as harmful even though they are both expected and planned for.

Further, spectrum users also expect a certain level of interference from other users or from electrical equipment. Expectations between users and uses will vary as with interruptions caused by natural phenomena, however the addition of the term 'expected' notes that there is the possibility of interference being caused which is not immediately considered as harmful.

The addition of the concept of reasonableness

The reasonable person standard is an oft used legal term that originated in the development of common law. The "reasonable person" is a hypothetical individual who is intended to represent an "average" citizen. The ability of this hypothetical individual to understand matters if consulted in the process of making decisions of law. The question, "How would a reasonable person act under the same or similar circumstances" performs a critical role in legal reasoning in areas such as negligence and contract law.

The reasonable person is appropriately informed, capable, aware of the law, and fair-minded. The rationale for the reasonable person standard is that the law will benefit the general public when it serves its reasonable members, and thus a reasonable application of the law is sought, compatible with planning, working, or getting along with others. Thus including reasonable expectations of interference is highly relevant when one considers that radio users must plan, work and get along with others.

3.4.2 Non-interference and non-protected use

Texts reviewed in this context include implementing Decisions under the RSD taken by the European Commission with the assistance of the Radio Spectrum Committee. Some implementing Decisions (see 3.1.3) have been identified as having inconsistent and potentially misleading use of the term “harmful interference”.

Recommendation 3.2: The definition of harmful interference requirements and variations thereof in individual Commission Decisions should be harmonised and existing Decisions should be amended accordingly.

It is accepted that use of the term “non-protected” may be useful to emphasise that certain communications by means of radio waves in spectrum subject to a particular Commission Decision are not “radiocommunication” for the purposes of the harmful interference definition. However, current use of this term is not consistent. Three possible meanings emerge:

- protection is denied in respect of any other systems or services operating in the same band (which in current context is interpreted as meaning operating under the same Commission Decision);
- protection is denied only in respect of systems or services of the same type operating in the same band; and
- protection is denied in respect of all emissions (interference) arising from radio equipment operating in accordance with the applicable Community or national legislation.

In all three cases, protection is denied even if the emissions concerned would otherwise qualify as “harmful interference”.

The consultant takes the view that there is justification for non-protected status in relation to unlicensed / licence-exempt spectrum. Enforcement agencies cannot reasonably be expected to arbitrate in interference disputes between individual users of such spectrum. Devices which operate under these terms must accept interference from all other users of the spectrum, whether licensed or unlicensed / licence-exempt. However, in all cases, users should be protected against equipment that is not operating in accordance with the applicable Community or national legislation.

Recommendation 3.3: The use of "non-protected" in each relevant Commission Decision should be aligned on the following basis:

Non-protected basis means that no claim may be made for protection from interference received from radiocommunications operating in the frequency bands subject to this Decision and in accordance with the applicable Community or national legislation.

In this formulation, protection is denied only from radio communications and not other forms of electromagnetic disturbance so that the usual EMC protection will otherwise apply. Also, protection is denied only when the offending equipment is operating in accordance with the relevant Community or national legislation.

3.4.3 Impact on legal measures

These recommendations will require changes in the Authorisation Directive, the R&TTE Directive and a number[30] of Commission Decisions comprising technical implementing measures under the Radio Spectrum Decision. These changes are discussed in more detail in Section 5 of this report dealing with legal measures. Essentially, they introduce the new definitions together with any consequential editorial changes and appropriate explanatory recitals.

The recommendations have a consequential impact on the EMC Directive which, in its present form, fails to recognise the possibility of harmful interference from electrical and electronic equipment in its scope. This means that enforcement action in such situations must be made on the basis of "electromagnetic disturbance" rather than with specific powers for harmful interference.

Recommendation 3.4: The EMC Directive should be amended to recognise the specific concept of harmful interference in order to recognise the possibility of harmful interference from electrical and electronic equipment.

[30] 2007/131/EC on allowing the use of the radio spectrum for equipment using ultra-wideband (UWB) technology in a harmonised manner in the Community ; 2007/98/EC on the harmonised use of radio spectrum in the 2 GHz frequency bands for the implementation of systems providing mobile satellite services (MSS) ; 2006/804/EC on harmonisation of the radio spectrum for radio frequency identification (RFID) devices operating in the ultra high frequency (UHF) band ; 2006/771/EC on the harmonisation of the radio spectrum for use by short-range devices (SRD) ; 2005/50/EC on the harmonisation of the 24 GHz range radio spectrum band for the time-limited use by automotive short-range radar equipment in the Community ; 2004/545/EC on the harmonisation of radio spectrum in the 79 GHz range for the use of automotive short-range radar equipment in the Community.

3.4.4 Introduction of a Market-Based Approach to Harmful Interference

None of the foregoing precludes the introduction of market-based negotiations of interference levels. As spectrum trading continues to be refined and rolled-out, there is an increased need to define the rights and obligations of spectrum users. The proposed 'accepted interference' based rights would compliment many of the other rights currently recognised or under consideration and would afford users a certainty of 'quality of spectrum' unless they were agreeable to a change.

Recommendation 3.5: The European Commission should work with spectrum users to produce an agreed technical definition for 'permissible interference'. Our suggested starting point is a 0.42 dB rise in r.m.s. noise or 10% increase in outage.

Recommendation 3.6: The Commission should ensure that in the revision of licences to allow for liberalisation, the concept of a negotiated accepted interference approach is one of the possible ways in which spectrum users rights can be defined.

3.5 Reporting and Recording of Interference

3.5.1 Introduction

During discussions in the EMC Working Party and in the joint CENELEC/ETSI working Group addressing Mandate 313 matters, it has been suggested on a number of occasions that NRAs receive only a minimal number of complaints of interference arising from unintentional radiators. The inference drawn is that current EMC standards must be about right given the quantity of IT and electrical equipment now in daily use.

Harmful Interference has been defined earlier as meaning interference which endangers the functioning of radiocommunication to an extent beyond that which would be reasonably expected when operating in accordance with applicable Community or national regulations. In order to achieve such an effect the signal to noise ratio or bit error rate will be degraded to such an extent and for such periods of time that the radiocommunications service is unacceptably disturbed.

Harmful interference may arise from distant or nearby stations utilising the same or adjacent frequencies or from nearby electrical or electronic equipment radiating electromagnetic emissions. Any of these potential sources may degrade unacceptably the signal to noise ratio or bit error rate of the wanted signal.

If the statistics provided by the Finnish NRA reflect the general situation in Europe then some 20% of complaints arise from electrical equipment, with 25% of these occurring as a result of ISM apparatus or IT equipment.

This is an important point since the next step must be to postulate whether or not:

- the radiation from IT equipment is significantly less than the current generic EMC limits; or
- the current generation of radiocommunication equipment is more resilient to interference than its predecessors; or

- radiocommunication users manage the problems of interference in other ways; or
- there has become a general acceptance of the problems of interference such that complaints are less frequently raised.

If the conclusion is that modern, digital radiocommunication equipment can better cope with interference than in the analogue era, then perhaps the criteria used for planning radio services might facilitate more sharing of the available spectrum. Alternatively, it might be possible to lower the standards which limit emissions from non-radio equipment thus reducing equipment costs.

However none of these actions can be contemplated without hard evidence to support which of the four possible scenarios presented above is actually taking place. This requires more focus on reporting and recording interference complaints which arise, and to a lesser extent, encouraging the reporting of interference.

3.5.2 Interference Reporting

Interference reporting is the means by which radiocommunications users can identify interference and then report their problems to the NRA. In a digital environment it is likely that quality of service issues may not be associated with interference. A user may experience an overall increase in the noise floor or a system outage, which may be attributed to other non-interference effects. For example, interference to analogue television services often takes the form of patterns on the picture which are obtrusive to different degrees, whereas interference to digital television services can result in a blank screen, which is not intuitively likely to be attributed to interference. Furthermore, it is possible that some radiocommunications users may not interpret problems to or from ADSL or cable TV as radio interference. In this case the only impact on a user is likely to be degraded download speeds, easily confused with other fault conditions. The scenarios postulated could easily lead to an under-reporting of the problem.

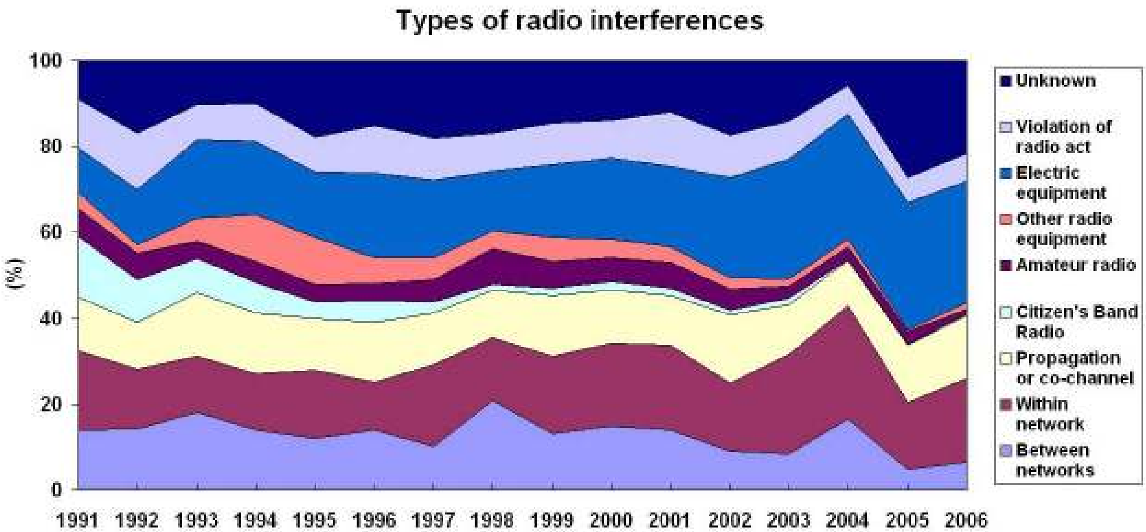
It is also possible for users to take mitigation measures such as turning off sources of interference within their control or accepting a degraded quality of service. Lastly the point has been made that recent changes in regulators' methods of working may not stimulate the reporting of interference cases as discussed during the first project workshop. Reasons cited include:

- A reduction in engineering staff able to respond to and solve interference problems;
- Prioritising interference cases such that some radiocommunications users experience long delays before their problem is investigated;
- The introduction of schemes to obtain funds from licensees (in addition to their licence charge) to pay for the resolution of interference problems; and
- Reorganisation of the national regulatory environment in such a manner that non-licensees are not aware of how to identify and report interference problems from various sources. This is especially important in the case of interference to radio and television broadcasting reception.

3.5.3 Interference Recording

During the first workshop interference reporting and recording was discussed and four regulatory bodies from Finland, Germany, Sweden and the United Kingdom suggested that the number of reported cases of interference had been declining in recent years. Indeed at the first workshop, Ofcom from the United Kingdom stated that it had established a system of measuring EMC across various bands. This system was used to categorise interference and noise parameters for defining spectrum usage rights which were planned for the introduction of Ultra Wide Band radio systems. Initial results suggested there were minimal problems; interference was very localised; and that levels were within the range set by the ITU.

Subsequent to the workshop the Finnish NRA, FICORA provided some detailed statistics of interference complaints in percentage terms of different types, in the period 1991 to 2006. It is interesting to note that the worst category for causing interference to radiocommunications services, which are not part of the same network, arises from electrical equipment. Looking a little more closely at this category reveals that the main problems occur from an electrical appliance or installation which is not ISM or IT apparatus.

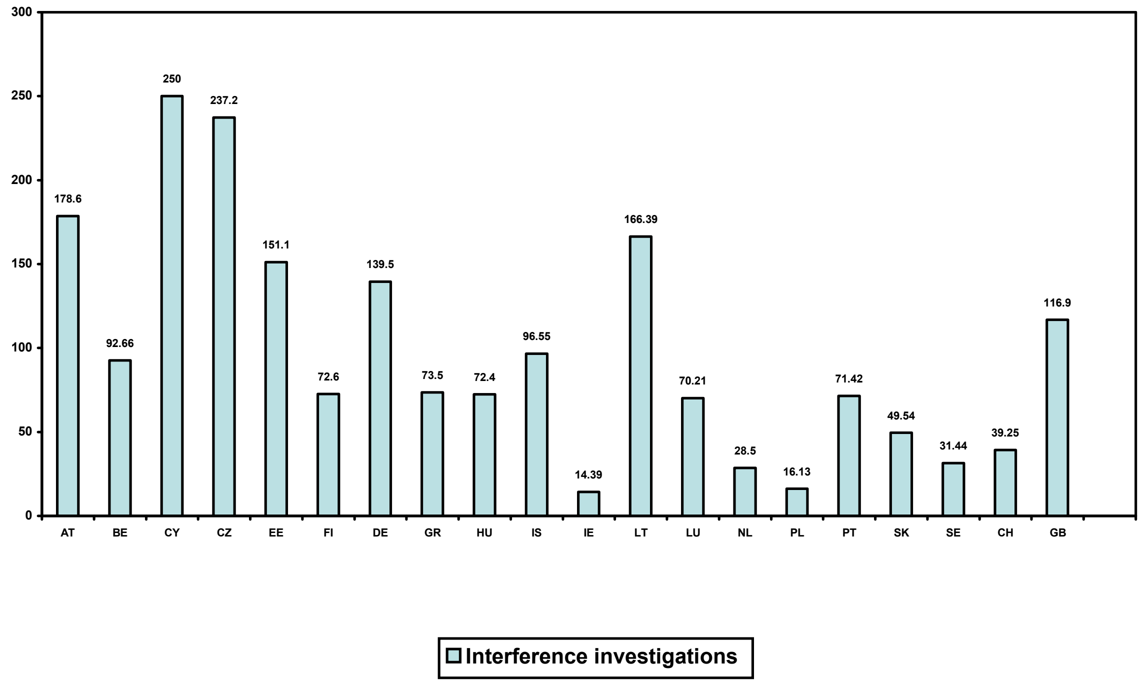


CEPT, in Working Group RA, has also been analysing interference trends as well as conducting a benchmarking exercise on Europe's enforcement authorities. The purpose of the interference study was to determine whether the introduction of new approach EMC and R&TTE Directives had contributed significantly to the reduction. The study reports that there appears to be a general decline in interference complaints, particularly with respect to PMR services. Only one out of 11 CEPT members reported an overall increase. Specific problem areas were surfacing generally in unlicensed bands where short range devices, LAN and WiFi equipment were operating. It appears that the main source of these problems is generally of an EMC nature.

The main reason provided for an overall decrease in interference complaints concerns the introduction of new technologies, which (it is said) is related to the progressive harmonisation of standards and frequencies. However the question has to be posed as to whether this situation actually reflects a diminution in interference or whether service degradation goes unreported or is not identified as interference by the user. One administration stressed the benefits of public awareness campaigns which had helped significantly in removing non-compliant products from the market.

As part of the benchmarking exercise, administrations were requested to provide details of the number of interference cases addressed for various types of service. This proved difficult due to the variation in reporting methods across Europe. A comment in the report drew attention to the large variation in the numbers of cases even when population differences where taken into account. This tends to suggest that some of the additional factors mentioned in 3.5.2 above may be influencing the statistics in some countries.

The following chart taken from the Benchmarking Report reflects the situation of interference investigations conducted in 2004 per million of population.



Total number of investigations, adjusted to show the number of investigations per million of population

A further important point was raised at the Workshop: At present, EMC problems tend to diminish in the upper part of the UHF spectrum, whereas they can create considerable problems in the LF, MF, HF and VHF bands.

3.5.4 Situation in other Countries

It seems that interference reporting, recording and resolution do not have a particularly high priority in many countries although it is unclear what arrangements are available for resolving interference events for essential services.

In Canada, Industry Canada (IC) the telecommunications regulator at one time conducted investigations to identify and locate sources of radio interference but no longer provides this service. IC states that the changing climate in government has caused a re-examination of role and objectives and as a consequence it no longer provides services that are considered non-essential or are more appropriately delivered by the private sector. The identification and location of interference is one of those services. Fact sheets on interference resolution are available.

In Australia, ACMA provides advice in the shape of fact sheets as well as an investigation service. A fee is charged unless the problem is community wide, or the plaintiff has independently engaged a qualified technician, who has determined that the source of interference is not in the home or premises of the plaintiff. Solving interference problems is the responsibility of the affected parties, except where there are breaches of the Radiocommunications Act 1992 and Telecommunications Act 1997.

In the United States, the FCC Enforcement Bureau resolves complaints, investigates and takes enforcement action for violations of the Communications Act and/or Commission rules resulting in radio frequency interference. The Consumer and Governmental Affairs bureau issues a fact sheet for consumers concerning interference.

3.5.5 Observations

Despite the position taken outside Europe, It seems clear that the reporting and recording of interference is an importance piece of market surveillance information. Unless radiocommunications users are encouraged to report significant interference problems, it is somewhat difficult to balance some of the statements discussed in previous sections. On the other hand licensees will expect value for money in terms of their licence costs and will not wish to see a significant increase in the administrative charge element of individual licences. A balanced approach is therefore required.

3.5.6 Keeping abreast of Interference – Next Steps and Recommendations

It can be seen that the general global trend is to move the resolution of interference in the community from regulatory intervention to self-help or sector resolution by manufacturers or installers. Whilst this is excellent news for those who will benefit from cheaper regulatory costs, it appears to offer little help in the collection of accurate statistics relating to the real situation concerning interference levels in Europe. The points raised in 3.5.2 and confirmed in the CEPT report may still be pertinent. Furthermore, as portrayed in the chart in section 3.5.3 there are unexplained differences concerning the level of investigations in various Member States. As a minimum it would appear beneficial to have a common approach to recording and reporting interference events throughout the EU.

Let us also recall why this issue may be important in the context of overall interference management. In essence there is a school of thought which believes that, because very few complaints of interference from IT apparatus are reported despite the existence of many millions of such devices in the field, the EMC limits for such devices could be used as a basis for developing the noise component used in planning radiocommunications services. Or in other words the ‘unwanted signal’ interference models used for planning are far too conservative.

It therefore seems important that interference is given wide publicity; it is the pollution of the spectrum management world and can affect all. Eurostrategies therefore believes that a study addressing interference management would be incomplete without some detailed consideration of the subject.

Recommendation 3.7: CEPT, the Commission and national regulatory authorities should consider means of obtaining benchmark interference statistics and a common approach for recording and reporting trends. Furthermore, such statistics should be publicly available for study and comparison with the situation outside Europe.

In recent years there have been several examples of explanatory booklets and web-pages, which describe interference effects in layman terms. It would seem feasible to develop an appropriate booklet for Europe and associated report form based on local conditions. An example of such a booklet has been prepared and is attached at Annex C to the present report. Such a booklet should be easily accessible through public institutions such as town halls, commune offices, post offices or public libraries as well as the Internet. It should also describe simple ways of alleviating basic interference problems to avoid involving the NRA if at all possible. An interference notification form with local details should be designed to report interference experienced, as well as a means developed to categorise the problem in terms of annoyance levels and whether the problem is continuous or sporadic in nature.

There should also be an ‘interference awareness’ campaign but this needs to be proportionate and measured to avoid undue costs. Again post offices and public libraries may be able to help in this regard. Broadcasters, operators and sector trade associations should also be requested to raise awareness of interference issues via their customers and members. A short form of the Interference Information Sheet has been developed which could appear on notice boards in public buildings directing the public to the more comprehensive interference information sheet. This has been attached at Annex D.

Recommendation 3.8: Annexes C and D to this report should be considered as a basis for a possible common European approach to promote public awareness in radio interference, to provide information on how to solve simple interference problems and to inform the public about the organisation responsible for these matters in Member States.

4. Review of Compatibility Studies

4.1 Introduction

Section 4 can be divided into two distinct parts. In Sections 4.2 to 4.4 the current process in Europe is examined where compatibility analyses are conducted by CEPT, either as part of its technical work programme or as mandated studies from the European Commission and recommendations concerning the current process have been made. In Section 4.5 onwards a more radical approach has been taken where options for involving bodies other than CEPT have been examined with a view to improving and extending the CEPT process. In both cases the use of a risk and vulnerability analysis has been considered. Such tools are regularly used in other industries to balance risk and performance, see Section 7.

One of the key goals of compatibility studies is to produce a predictable environment and an interference situation between users and services which facilitates the efficient and effective use of the spectrum. Compatibility should not be confused with co-ordination, especially in an international context. Co-ordination is generally considered to be a trigger mechanism to ascertain whether compatibility or mitigation studies need to be initiated in particular frequency sharing situations. In general, the process of co-ordination requires a calculation which determines whether a trigger field strength or power flux density (PFD) is exceeded at a certain geographical point using agreed calculation methods. If the co-ordination trigger is exceeded, a dialogue ensues to determine whether the station can be implemented with the characteristics requested.

Compatibility analyses on the other hand, assess the actual compatibility between systems. To conduct an analysis it is necessary to specify a system performance criterion which must not be degraded beyond a desired minimum level. This can usually be related to the maximum permissible level of received interference power in a reference bandwidth, or the minimum value for the carrier to interference (C/I) ratio. By using either of these parameters, together with a suitable propagation model and the effective radiated power of the interfering source (in the direction of the receiver to be protected), the minimum separation distance between the different systems can be calculated. It is also necessary to take account of the likely number of interference sources that will contribute to a degradation of the C/I ratio.

However this is not the end of the story as a compatibility analysis is in many cases about planning a future system or platform before it has been developed. Thus some of the parameters may not be fully defined at the time of the analysis. Some analyses concern the compatibility between licence exempt systems and incumbent licensed users. In such cases it is necessary to know the number of devices likely to be involved as this will set the interference model to be used. Assessments of the likely market will also be needed in order to assess any necessary changes to the model over time.

Furthermore, the radio spectrum can only be used in an optimal manner if harmful interference is minimised between users and radio systems in the same or adjacent frequency bands. The increasing use of digital signals in radiocommunications systems implies that an increasing number of radiated emissions will have a stochastic character (non-deterministic or random) and will thus require characterisation by means of statistical methods. To assess the probability of interference occurring, statistical modelling of interference scenarios is required. Here interference will be expressed in terms of the probability that the reception capability of the victim receiver is impaired by the presence of an interferer.

4.1.1 The Basic Compatibility Model

The compatibility model is derived from a series of system loss/gain equations combined into a single equation which enables the separation distance to be calculated.

Power level received from the interfering source

The example considered comprises a number of transmitters which should be considered as potential interfering sources; the received power into the victim receiver is given by the following equations:

Equation 1 $P_a - T_a + G_a(\varphi°) - L_{av} - B_a + G_{v1}(\theta°)$

Equation 2 $P_b - T_b + G_b(\varphi°) - L_{bv} - B_b + G_{v2}(\theta°)$

Where:

P_a, P_b = *Power at victim receiver (dBW/Hz)*

T_a, T_b = *Power from interfering sources (dBW/Hz)*

G_a, G_b = *Gain of interferer's antenna in direction φ° of victim receiver (dBi)*

L_{av}, L_{bv} = *Path loss between interfering source and victim receiver (dB)*

B_a, B_b = *Building penetration loss (if applicable) (dB)*

$G_{v1}(\theta°), G_{v2}(\theta°)$ = *Gain of victim's antenna in direction θ° of interferer's transmitter (dBi)*

Minimum attenuation required between systems

By substituting the maximum permissible interference power level (Ip) for the victim service for the terms P_a and P_b in equations 1 and 2 above, and rearranging, equations can be obtained for the required attenuation between systems:

Equation 3 $L_{av} > T_a + G_a(\varphi°) - B_a + G_{v1}(\theta°) - Ip$

and

Equation 4 $L_{bv} > T_b + G_b(\varphi°) - B_b + G_{v2}(\theta°) - Ip$

Where:

Ip = Maximum permissible interference

Geographical separation requirements

The necessary isolation can be provided by the propagation loss obtained by geographical separation of the systems. A first approximation of the minimum separation distance can be determined by using the simple free space path loss equation:

Equation 5 $L_{av} = 92.44 + 20 \log(f) + 20 \log(d_{av})$ (dB)

and

Equation 6 $L_{bv} = 92.44 + 20 \log(f) + 20 \log(d_{bv})$ (dB)

where

f = frequency (GHz); d = distance (km).

Alternatively, more detailed propagation models can be used which take into account shielding, diffraction loss, urban clutter, etc.

4.1.2 Refining the Model

Problems arise when several systems, perhaps utilising different technologies, operate in the same or a neighbouring geographical area and in addition are using adjacent frequency bands. In such cases traditional analytical methods often cannot provide a satisfactory solution. An alternative is to express the level of interference in terms of the probability that the reception capability of the victim receiver is impaired by the presence of an interferer. To arrive at this probability of interference, statistical modelling of interference scenarios is required.

To provide a tool for statistical modelling SEAMCAT (Spectrum Engineering Advanced Monte-Carlo Analysis Tool) first released in 2000, was developed by a group of CEPT Administrations, ETSI members and international scientific bodies. The term "Monte-Carlo" was adopted by von Neumann and Ulan during World War II, as a codename for secret work on solving statistical problems related to atomic bomb design. Since that time, the Monte-Carlo method has been used for the simulation of random processes and is based upon the principle of taking samples of random variables from their defined probability density functions. The method is often described as the most powerful and commonly used technique for analysing complex statistical problems. The approach is flexible and can address a variety of interference scenarios.

In SEAMCAT the level of interference between different radio systems is expressed in terms of a probability that the reception capability of the receiver under consideration is impaired by the presence of an interferer. Any interference scenario, regardless of the type of victim and interfering radio systems can be analysed. This is helpful in developing appropriate frequency planning arrangements or developing limits for transmitter/receiver parameters.

During one interview conducted as part of the study, the view was expressed that since its launch in 2000 the SEAMCAT software has been extended with a number of additional modules to facilitate compatibility studies as new requirements have emerged. As a result it was suggested that the software has become rather ‘user unfriendly’ with the result that only persons with an in-depth knowledge of SEAMCAT are able to use it in an effective manner.

4.1.3 Other Compatibility Factors

Whilst the use of statistical modelling certainly improves the accuracy of compatibility calculations, it is possible to refine the modelling still further for terrestrial radiocommunications services at the local level. Local factors to be addressed in the propagation model might include terrain and building information, building penetration and in some cases climatic information etc. Propagation information is often the weak link especially where the level of interference is computed from a number of point sources, which may be subject to varying propagation influences. To provide the modelling software with accurate data may require a number of measurements over significant periods of time.

This leads to the question of whether it would be preferential to consider specifying power flux density masks at receiving stations (for non safety purposes) rather than the use of complex compatibility analyses conducted by Regulators and Spectrum Management organisations, when considering the introduction of new systems with incumbent users.

4.1.4 Radio Planning

As well as addressing the issue of reduced C/I margins as a consequence of introducing new systems or services in the same or adjacent spectrum, it is necessary to examine the planning criteria used for planning the wanted service and investigate whether new techniques might be introduced which facilitate a more efficient use of the spectrum through the use of lower power levels and a consequential reduction of interference. Examples include a reduction of fade margins, improved side lobe response of antennas where appropriate or applicable.

4.2 Detailed Review of ECC Compatibility Studies

4.2.1 Introduction

Annex B to the present document lists recent CEPT ECC Reports dealing with compatibility issues which have been examined during the course of this study. These cover the period from February 2002 to August 2007.

The ECC (the Electronic Communications Committee) was created in September 2001 when the previous European Radiocommunications Committee (ERC) was merged with ECTRA into the ECC. Although the CEPT ERC series of reports covering the period 1991 to 2001 also includes a number of compatibility studies; these were not addressed for two reasons. Firstly, a number of these reports address systems and technologies, which are no longer in existence, such as ERMES, DSRR and TFTS. Secondly, SEAMCAT, the Monte Carlo analysis tool, was not available for the majority of the earlier compatibility studies which implies that the analyses were based on worst case scenarios.

4.2.2 Background

Compatibility analyses are currently conducted within CEPT constituent bodies and are initiated either as a result of an initiative originating in CEPT or ETSI, or under a specific mandate from the European Commission. In the case of a study initiated within CEPT such a technical analysis is performed in a project team established by the Spectrum Engineering Working Group, which will subsequently approve its report after public consultation. Companion decisions or recommendations on frequency management or regulatory activities may be addressed in a CEPT Recommendation or Decision.

In the case of a Commission mandate, any analysis shall be approved by the ECC, which (it is understood) introduces unacceptable delays. Since the adoption of the Radio Spectrum Decision in 2002, it is clear that policy relating to spectrum management shall be developed by the Commission taking account of advice provided by *inter alia* the Radio Spectrum Committee and the Radio Spectrum Policy Group (RSPG). Under the RSD; technical implementing measures can be mandated to CEPT.

4.2.3 Discussion and Findings

The studies listed in Annex B cover the frequency range from 130 kHz - 78 GHz. They include a variety of systems and services as well as diverse power levels. In some cases likely interference zones are large whilst in other cases ultra low power SRDs are involved and consequently interference zones are small. In a number of cases conventional as well as Monte Carlo simulations have been conducted. Column 4 of the table in Annex B is entitled Result: There are 4 possible results, ‘yes’ (Y) where no or minimal compatibility constraints will be needed, ‘yes with restrictions’ (YR) where sharing is envisaged with minimal compatibility constraints if advocated measures are implemented, ‘yes marginal’ (YM) where quite onerous constraints would be needed and No (N) where no sharing is possible.

Many sharing scenarios are predicated on a requirement for frequency separation and/or spatial separation. In some cases additional filtering may be required at the transmitter or receiver. Duty cycle is also a mitigation measure postulated in some reports. This means that sharing might be possible if the transmitter is required not to key-up for specified periods of time. In some scenarios certain types of service might not be possible for example if the interfering signal is located on an aircraft.

Although the compatibility studies are of a technical nature some regulatory measures are postulated. A good example might be where sharing with radio astronomy could not be sanctioned unless transmitters were deactivated at a defined distance from the observatory. The use of antenna discrimination is also suggested where an increase in EIRP would be permitted provided it resulted from using a higher gain antenna, which would result in reduced side-lobe power.

A particularly interesting situation arises in ECC Report 64 dealing with Ultra Wide Band. Here the compatibility studies including the SEAMCAT analysis suggested that to provide adequate protection for existing services would require 20-30 dB more protection than the mask adopted in the United States by the FCC. The ECC subsequently took a regulatory/political decision that such a level of protection was not required and approved a CEPT ECC Decision which accepts most of the parameters adopted for UWB in the United States below 10 GHz.

4.3 Compatibility Studies – The Way Forward

4.3.1 General

The compatibility studies performed by CEPT under the auspices of the ECC work programme or when mandated by the European Commission appear generally to conform to good engineering practice and would be recognised by most spectrum managers around the world.

In order to improve access to spectrum by means of interference management techniques it will be necessary to consider the planning process for some radio services, including fade margins, quality of service and antenna performance as well as other technical measures which can be introduced. In addition it is necessary to address the efficacy of EMC limits from electrical and electronic equipment in protecting radiocommunications networks, services and systems. Administrative and regulatory processes and procedures will also have a place in interference management.

It is likely that all these measures may facilitate the concept of C/I PFD masks at the victim receiver or antenna using techniques to determine whether new technologies and systems can be introduced to a frequency band. Where detailed terrain height and ground cover information is available, deterministic models may be applied to accurately calculate attenuation along the interference path using computer based prediction tools.

4.3.2 Identified Problem Areas

A review of progress for several mandated compatibility studies would appear to indicate that there is an apparent loss of time in the CEPT process, between the formal issuing of an EC mandate and the CEPT Final Report. On the other hand CEPT over a period of time has reduced its permanent committee structure to two levels, Working Groups and a Committee, the latter addressing all issues relating to electronic communications. Key work is performed in temporary Project Teams, established to undertake a specific task, which provide texts to the Working Group for approval. Mandated Commission work is also passed to the ECC for final approval.

This leads to a situation where the time not actually spent on the compatibility studies ranges between 40% and 100% of the duration of the mandate[31]. This is not surprising when up to 9 meetings may be required to reflect the process of preparing a CEPT Report in response to an EC Mandate according to the ECC's Working Methods document. This assumes that a Project Team is established and an Interim Report prepared. A simple solution would perhaps be for CEPT members to agree that a Project Team established to prepare a mandated response should present the document to the RSC for comment at an early stage, rather than progressing sequentially backwards and forwards through the CEPT hierarchy, before a formal delivery to the RSC by the ECC. Alternatively the ECC has within its Rules of Procedure the option to establish a Project Team itself and this might be a quicker and preferable route for developing a CEPT Report for approval by the ECC.

One of CEPT's strengths in the past has been the ability to reach consensus and arriving at European positions on difficult spectrum management questions. Consensus has often been reached through compromise, where individual countries or administrations had strong national positions or interests. And if any question is referred to the ECC for approval, it is the CEPT members who will take the final decision, in some cases by a vote. It is unfortunate that in many cases administrations have not implemented the CEPT Decisions and Recommendations agreed by this consensus process. In any event such an approval and implementation process may not be considered sufficiently transparent in the 21st century for determining some regulatory or semi-political issues.

An examination of some of the mandated compatibility studies initiated by the European Commission suggests that it is not only technical decisions that have been taken within CEPT in defining whether compatibility is or is not feasible or whether mitigation measures need to be triggered. In addition, assumptions have been made on possible market size and future development, which are not strictly technical but rather of a regulatory or socio economic nature.

Unless there is a fundamental review, simplification and consolidation of the European telecommunications regulatory processes, the issue of how to overcome the difficulties described above will remain. In terms of future compatibility studies conducted by CEPT it is suggested that a number of different scenarios should be assessed if non-technical information needs to be utilised in an analysis. One approach would be for CEPT to provide a range of options and scenarios based on technical assessments in order for a political or socio-economic decision to be taken invoking Community procedures, policies and processes, notably in discussions between the Commission and Member States in the Radio Spectrum Committee. Alternatively, market and other relevant non-technical information could be provided by the Commission, using agreed processes and procedures, for discussions with the radiocommunications sectors and users involved in a particular analysis.

There are also potential alternative approaches to compatibility studies, which are discussed in Section 4.5.

[31] The latter in the case of "posthumous" mandates, i.e. where the technical compatibility had already been carried out by CEPT before the EC mandate, for instance for MCA, and where therefore the near-totality of the time is spent in obtaining approval for the deliverable at the various levels of CEPT.

4.3.3 CEPT Mandates

Concerning mandates, it is necessary to underline that the European Commission is competent with respect to radio spectrum policy issues, co-ordination of policy approaches and, where appropriate, the harmonisation of conditions with regard to the availability and efficient use of radio spectrum necessary for the establishment and functioning of the internal market. Methods are in place to consult extensively in a forward-looking manner on technological, market and regulatory developments relating to the use of radio spectrum in the context of EU policies on electronic communications, transport and research and development.

On the question of technical implementation methods pertaining to the use of spectrum, mandates are issued to CEPT. It is believed necessary to outline a framework for such studies. Current mandates commence with the purpose, justification, policy objectives and specific objectives relating to the mandate. These should continue to feature in the mandate. However when it comes to developing sharing scenarios and technical regulatory conditions, mandates are sometimes not specific.

It is suggested that in further developing the template for mandates the following text is included in the first paragraph of the section entitled, ‘Order and Schedule’ (example):

‘CEPT is mandated to undertake the activities specified below. These are intended to support the objectives and policies detailed above, within the framework of the Maastricht 2002 Special Arrangement. It is stressed that these activities should be limited to matters of a technical nature which assess compatibility and sharing issues between existing services utilising frequencies within and adjacent to the band in question. If considered appropriate to the technical analysis, various scenarios or options should be clearly presented. If market size is considered to be an issue this should be indicated and included as one or several additional options for consideration. The specific activities to be performed are to:’

4.3.4 Possible improvements to the process

Future compatibility analyses might also, where appropriate, include a vulnerability analysis which might be performed by computer modelling and laboratory measurements. A vulnerability programme includes a collection of technical information and procedures that form a detailed process, the components of which may vary according to specific cases. However the core approach usually follows a common path and includes the following steps:

Step	Description
1	Determine priorities for interference mitigation
2	Determine receiver sensitivity characteristics
3	Evaluate the risks
4	Develop appropriate modelling and measurement plan
5	Evaluate effectiveness

4.3.5 Form of Assessment

In this section we detail the elements of assessment, which are believed to be necessary once a compatibility analysis has been delivered by CEPT in the form of a CEPT Report, which responds to a Commission mandate.

Subsequent to receiving a technical compatibility analysis from CEPT, the Commission could consider performing an impact assessment of regulatory and socio-economic factors.

Firstly it is necessary to identify and outline the overall purpose and effect of the compatibility analysis. In this section it will be necessary to outline the objective, background, conduct a risk assessment with the following or similar steps:

Step	Description
1	Identify pertinent socio-economic issues
2	Decide the possible impact of these issues on the technical compatibility study
3	Evaluate the risks and decide on any acceptable non technical mitigation measures
4	Document the processes used
5	Review the assessment and update if necessary

It will also be necessary to detail the actors and business sectors involved - including market issues, any issues of equity and fairness arising and lastly any other regulatory or socio economic issues which should be considered.

It is then necessary to analyse the options provided in the technical compatibility study; option 1 should address the possibility of maintaining the status quo. Sections should then follow which analyse the various options in respect of benefits and the costs involved for concerned parties.

Once a cost-benefit analysis has been conducted the assessment should address any consultations which have been carried out, competition issues and the mechanisms for monitoring and periodic review of the assessment.

Lastly there will need to be a summary and any recommendations arising from the assessment.

4.3.6 Recommendations

The proposed establishment of a European Electronic Communications Market Authority (EECMA) and the current on-going process of CEPT reform may provide opportunities for improvement in the current process.

In respect of compatibility analyses and taking account of mechanisms regularly used in other business environments, as well as the impact of introducing new radiocommunications applications (systems or services) as well as:

- The cost benefits of introducing innovative systems for European industry and users;

- The future market for electronic communications devices;
- The need to ensure adequate and interference free spectrum for governmental uses and applications providing social benefit;
- Technical compatibility issues; and
- The risk of unacceptable electromagnetic disturbances occurring;

we make the following recommendations:

Recommendation 4.1: The Commission should consider performing an impact and risk assessment on regulatory and socio-economic factors subsequent to a technical compatibility analysis by CEPT.

Recommendation 4.2: Mandates to CEPT should be specific in respect of requirements relating to sharing scenarios and technical regulatory conditions.

Recommendation 4.3: CEPT should be invited to propose a pragmatic working arrangement which would hasten the delivery of mandated reports to the Commission.

4.4 Transparency and Process Development

There are a number of possible alternative approaches concerning how compatibility studies are conducted, which might be seen as providing more transparency, reliability and objectivity to the compatibility process. This was an issue raised in the Consultant's request for views from the sector, in respect of interference management issues. It was for example postulated whether some studies conducted in Member States may not have been entirely objective and the overall approval process of CEPT Reports not sufficiently open. In this section an examination is made of possible alternative approaches to the CEPT model of compatibility analysis, as well as introducing empirical testing through modelling, laboratory testing or field trials.

4.4.1 Extending the ETSI Standardisation Process

As discussed previously in Section 2, ETSI already has an interface with CEPT when a new standard making process is initiated, which may require spectrum. ETSI is a body whose members come from industry, users and administrations. This raises the question whether conducting a compatibility analysis involving another radiocommunications application in a sharing or adjacent band situation would be more acceptable if it were to be conducted in ETSI.

Advantages might be:

- Greater perceived transparency in the compatibility process for some ETSI members;
- Less likely that the national interests of individual (or a group of) administrations would influence the outcome;
- A European approach is more likely to prevail;
- Those proposing the introduction of a new service or application would need to convince incumbents that sharing is feasible; and

- A decision would likely take place as a consequence of consensus according to ETSI democratic procedures.

Disadvantages might be:

- Government bodies or regulators may be considered more impartial than a body dominated by manufacturing interests;
- Not all radiocommunications users are represented in ETSI, especially governmental, emergency and scientific users;
- If a disputed compatibility analysis is decided by a vote, user interest may not prevail;
- ETSI would likely require funding for preparing analyses, CEPT studies are paid for by regulators or administrations; and
- The ERO public consultation process is open to all, whereas an ETSI public enquiry is normally limited to members or national associations.

4.4.2 Centralising European spectrum compatibility studies

As discussed in section 2.2.3 above, the ERO[32] was established by CEPT administrations as an intergovernmental European organisation in Copenhagen in 1991. The ERO is able to conduct any study that has been approved by the ERO or ETO Councils and the ECC. In the past it has managed three Detailed Spectrum Investigations as part of the process for developing the European Common Table of Frequency Allocations (ECA) and has conducted a number of studies for a non-CEPT client. There is therefore no reason why the ERO could not undertake detailed compatibility studies in support of Commission mandates under the procedure set out in the EU's Radio Spectrum Decision. However ERO has limited resources and has no laboratory, test equipment or technicians to support modelling, measurements or field activities. On the other hand one of the key activities envisaged for the ERO was to be an impartial interface between industry and administrations and it may be that this role could be strengthened. As noted earlier, the ERO is evolving towards a European Communications Office (ECO) which will embrace telecommunications and possibly postal matters, which fall within the CEPT remit.

Advantages might be:

- ERO may be considered impartial and independent of national administrations and regulators;
- ERO procedures and processes are open and transparent;
- ERO has been active in promoting a European approach to spectrum management; and
- ERO has a good record for consulting with industry and users;

Disadvantages might be:

[32] ERO is the organisation naturally used in this section since it is in operation and has experience in this activity. However, a similar case could be made for the European Electronic Communications Market Authority (EECMA), the new EU telecom Authority proposed by the Commission, although Art. 10.3 of the draft Regulation to establish the EECMA would seem to indicate that its activities would be without prejudice to those of the CEPT under the Radio Spectrum Decision.

- The ERO Council is an integral part of the ERO and comprises representatives of administrations and/or regulators and has a direct impact on budget and staffing;
- Larger administrations are able to influence major Council decisions through a weighted voting system;
- There is little evidence that the ERO Council has been in favour of expanding ERO beyond the scope of a secretariat for CEPT or increasing its budget over and above inflation for over 10 years; and
- Establishing and equipping a well maintained laboratory which is capable of conducting measurements and trials would require additional staffing and funding.

No doubt processes and procedures could be introduced to mitigate the problems of continuing with the existing approach where analyses are conducted by CEPT. Alternatively, if future compatibility analyses were conducted by a centralised function, means could be found to overcome any difficulties arising from such a development. However a more radical approach would be to utilise the private sector to perform any required compatibility analyses.

4.4.3 Private Sector Involvement

If efficiency, transparency and independence are of real concern compatibility analyses could be offered to private sector companies selected by a competitive tender process. It is envisaged that the Commission would provide market information, ETSI would provide the technical characteristics of the incoming service and CEPT would provide information on incumbent services. The scenarios to be tested would be detailed in the tender documentation.

A public consultation process on the outcome of the compatibility analysis would be required and this service could still be provided by ERO, as well as providing information and feedback on the process.

Advantages might be:

- Transparency would be ensured through the publication of information provided by CEPT, ETSI and the European Commission for tender purposes;
- Vested interests would have less opportunity for influencing the process;
- A European perspective would be maintained;
- The public consultation phase could be open to all; and
- The commercial entity conducting the analysis could liaise directly with incumbents.

Disadvantages might be:

- The process could prove to be more expensive;
- The Commission, ETSI or ERO would need to allocate resources for project managing the initiative;
- European organisations would require to provide input information in a timely manner; and

- Technical competence within administrations may be eroded.

4.4.4 Improving the CEPT Technical Process with EC Support

Sections 4.5.1 to 4.5.3 above have examined alternative ways to conduct compatibility analysis. However it is believed that the essential mechanisms used in the CEPT technical approach are fundamentally sound and are built on years of experience gained within the European administrations and NRAs. On the assumption that the recommendations in Section 4.4.6 are generally acceptable, it should therefore be considered whether the existing process could be refined with additional Commission involvement. This involvement might take the form of financial and practical support.
For example, an EU Spectrum Advisory Board (SAB) could be established comprising a number of independent experts providing advice to the Commission on:

- general developments concerning spectrum management;
- The content of EC mandates;
- CEPT deliverables pursuant to mandates (CEPT Reports);
- economic impact assessment before adopting EC Decisions[33].

In addition, the Commission might also consider providing financial and practical support to provide an effective EU central function for the modelling, laboratory analysis and field trials as appropriate to validate theoretical studies[34].

Advantages might be:

- Greater perceived transparency in the compatibility process;
- A European perspective would be maintained and strengthened;
- The injection of necessary economic data when appropriate;
- Better objectivity, accuracy and realism;
- Possibility of national administrations being assisted by European Community resources; and
- The process would sit well within the current regulatory framework i.e. Radio Spectrum Decision.

Disadvantages might be:

- Lack of transparency may still be an issue; and
- Processes may not be as speedy as envisaged under some of the other scenarios

[33] A possible mechanism to enable such activities seems to have been introduced in the recent Commission's proposal for a Regulation of the European Parliament and of the Council establishing the European Electronic Communications Market Authority (EECMA). See in particular Articles 10 to 13 on the proposed advisory role of the Authority concerning spectrum-related issues.

[34] A similar role is played in the US by the Institute for Telecommunication Sciences (ITS), see http://www.its.bldrdoc.gov/

4.4.5 Recommendations

It is not certain that there is a major problem with the conducting of compatibility analyses within Europe; but there appears to be some concern about transparency, timeliness and the fact that the current process seems to give CEPT the possibility to engage in regulatory- or policy-based decision-making beyond the compatibility analyses it is mandated to undertake in the context of interference management.

Our first recommendation therefore addresses the need for regular reviews and consultations concerning the actual process of managing spectrum, and for regular checks as to real concerns amongst industry and users concerning how the spectrum is managed and administered at national and European level.

Recommendation 4.4: Public reviews on a Europe-wide basis should be conducted at regular intervals concerning how the radio spectrum is managed and administered in Europe.

Since there are concerns with the current process of conducting compatibility analyses as has been discussed in the foregoing, a number of options could be envisaged. In developing the following recommendations careful note has been taken of the comments made during the second project Workshop held on 9 October 2007 where a number of possibilities were discussed. However the Consultant was concerned to find that there still appears to be a degree of friction, amongst representatives of national administrations, resulting from the current European regulatory situation. After more than 20 years of attempting to develop a cohesive European approach to spectrum management, it seems particularly timely to advocate a concept which will foster a closer working relationship between the concerned bodies. The Consultant has therefore opted for an approach based on the ideas expressed in Section 4.5.4 above.

The solution proposed would involve minimal change to the current process, CEPT procedures would be improved in a manner such that decisions would be based on clear European spectrum management objectives rather than those of individual Member States. However the Community would be actively involved in the process through the possible provision of additional independent expertise and practical and financial support. As well as the functions of the proposed new regulatory authority, EECMA mentioned above, another such means of support could be to use the services of the EC Directorate General Joint Research Centre (JRC) for the empirical work to support the theoretical analysis developed by CEPT.

The JRC provides scientific support to underpin EU policy making to provide added credibility. It has a wide range of competencies with broad skills in measurements, analysis and testing. Moreover, the JRC has a considerable understanding of the policy agenda since it is an integral part of the European Commission. The JRC also conducts high-level research in close co-operation with European industry and other bodies.

On behalf of the European Commission's Directorate General Health and Consumer Protection, the JRC is currently managing six Community Reference Laboratories (CRLs) on areas such as: GMOs in food and feed, feed additives, food contact materials, heavy metals in feed and food, mycotoxins in food and feed, and olycyclic aromatic hydrocarbons

The JRC has an Institute specialised on Reference Materials and Measurements (IRMM). The IRMM produces and distributes reference materials for quality assurance of testing laboratories, develops and validates methods of analysis, organises measurement evaluation programmes, and provides reference measurements and training. The areas of application are: food and feed safety and quality, biotechnology, sustainable agriculture, environment, health and nuclear safety and security.

It is worth noting that the JRC's Institute for the Protection and Security of the Citizen has already laboratories for EMC, radar and antenna measurements. Moreover, the JRC has performed co-existence measurements between collision avoidance UWB radars at 24 GHz and passive space-borne microwave radiometers.

Recommendation 4.5: The process of conducting theoretical technical compatibility analyses should continue under the auspices of CEPT ECC and its relevant constituent bodies.

Recommendation 4.6: The Commission should consider providing practical and financial support to the process.

Recommendation 4.7: Consideration should be given to forming an independent EU 'Spectrum Advisory Board' to provide advice to the Commission in complement to the CEPT activities. The proposed European Electronic Communications Market Authority could fulfil this role.

Recommendation 4.8: Vulnerability techniques should be considered as appropriate in future compatibility studies.

Recommendation 4.9: Consideration should be given by the Commission to offering the services of the Joint Research Centre to conduct laboratory and field measurements in support of compatibility analyses.

Recommendation 4.10: A public consultation exercise managed by ERO should be considered as part of any significant proposal for spectrum sharing.

Recommendation 4.11: The option to involve the private sector to undertake the analyses should be considered further if difficulties remain, in which case European standardisation bodies and an 'impartial ERO' should not be excluded from responding to any tender initiative to conduct compatibility studies.

4.5 Studies outside the European Organisations

4.5.1 ITU Studies

There is a vast array of compatibility studies and the development of sharing criteria between radiocommunications services in the documentation of the International Telecommunication Union. There is also information on the various modes of propagation as well as curves derived from long term measurement programmes in order to assess the likelihood of interference occurring over non line of sight paths. There are also reference antenna patterns for use when the actual antenna characteristics to be employed are unknown.

Most of the compatibility studies and sharing assessments are developed in response to study questions approved at an ITU Radiocommunication Assembly or as a result of a Resolution or Recommendation from an ITU World Radiocommunication Conference.

It is worth noting that Member States often input national compatibility assessments directly to the ITU Study Groups. In such cases a high degree of consensus building takes place, this time on the global stage with the participation of major non European countries. Again most countries will try and ensure that their national interests survive, often because of manufacturing interests and the value that industry places on securing favourable texts in ITU documentation, which can facilitate trade in foreign markets.

Where a compatibility analysis or the development of sharing criteria is required for an item on a WRC agenda the matter will be co-ordinated through CEPT's Conference Preparatory Group and may result in an input document to an ITU Conference Preparatory Meeting or a European Common Proposal (ECP) to an ITU WRC.

4.5.2 ICAO and other UN Specialised Agencies

Other bodies may undertake compatibility studies for a variety of reasons. The International Civil Aviation Organization is particularly interested in assessing any proposed sharing scenarios between aviation systems for the safety regularity of flight and non-aviation systems. ICAO has positively urged administrations that are referenced in footnote regulations in Article 5 of the ITU Radio Regulations (Table of Allocations) to remove themselves from such footnotes. This will generally be achieved by national aviation regulators lobbying at the national level, as a result of decisions reached in ICAO's global and regional forums.

Other specialised agencies of the United Nations such as IMO and WMO may also conduct similar technical studies.

4.5.3 United States

The situation in the United States is also interesting. Regulatory changes normally occur after a petition is received by the NRA for a change in the 'rules'. This would normally result in the FCC issuing a Notice of Proposed Rule Making (NPRM) to which any individual, company or organisation can submit comments. Both the NPRM and the reply comments may include compatibility analyses or the basis for proposed sharing criteria. These would normally be freely available to all interested parties. The Federal Government through the National Telecommunications and Information Agency (NTIA), which is responsible for managing the spectrum used by Federal agencies may also develop compatibility studies when Federal spectrum is involved.

4.5.4 Comparison between Europe and the United States

In the United States FCC Rules and Regulations, Title 47, Part 15 governs 'low power, short range' licence-exempt intentional radiators as well as unintentional radiators. The Part 15 approach seems to find favour with several respondents to Eurostrategies' survey.

Part 15 is somewhat similar to the EMC and R&TTE Directives. Both these Directives currently have an essential requirement relating to electromagnetic disturbance and harmful interference. However Eurostrategies has recommended that harmful interference should be recognised as a sub-set of electromagnetic disturbance and as such the EMC Directive should prevail in this regard. In the US most Part 15 equipment requires a declaration:

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This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.
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In other words, in both the US and Europe a regulatory condition is the overriding requirement.

In Europe a presumption of conformity is obtained if a declaration is made that the equipment conforms to a harmonised standard; it can then be placed on the market. However this does not obviate the need to comply with the essential requirements of the Directive. In the US certification (application with details of measurements against limits etc) for intentional radiators and a declaration of conformance for unintentional radiators is required before a product can be placed on the US market. Part 15 includes mandatory limits which are in general higher than Europe's harmonised standard limits; however again the overriding regulatory requirement is that the device should not cause harmful interference. Indeed it appears to be a common occurrence that the FCC issues enforcement letters concerning interference from Part 15 devices. Failure to rectify the situation can leave the user of a Part 15 device facing significant penalties.

In Europe it is unlikely that a similar enforcement regime would be applied. Many of the users which are likely to suffer from interference from unintentional radiators or short range devices are not provided with a high degree of protection by regulators.

In conclusion, although similar, the US Part 15 regulatory regime provides for higher power licence exempt devices but this is backed up by a vigilant enforcement bureau, with the power to impose penalties for rule infringements. The European approach requires that interference from unintentional radiators is not caused to radiocommunications users, but enforcement is left to individual Member States. The situation concerning any interference caused to licensed services by short range devices operating in harmonised bands in accordance with harmonised standards is currently rather unclear under the R&TTE regime and will be subject to the policy of individual member states. If Eurostrategies' recommendation concerning the use of the EMC Directive is accepted a clearer regulatory regime will prevail.

Recommendation 4.12: Any consideration for looking at a general increase in power levels for short range devices should take into account the important differences between the regulatory environments in Europe and the United States, especially in relation to the enforcement of the non-interference requirement.

5. Legal Issues

5.1 Constraints of Key Directives & the Radio Spectrum Decision

This section identifies those Directives where change is required to accommodate the specific proposals relating to harmful interference and compatibility models recommended in earlier sections of the report and the associated impact on the Radio Spectrum Decision.

The over-arching Framework Directive concerning electronic communication systems / networks imposes obligations on Member States regarding "…encouraging the efficient use and the effective management…" and to "…promote the harmonisation of use of radio frequencies across the Community". Of significance to this study is that the terms quoted here are not further qualified or defined leaving open the broadest possible interpretation. For example, the notion of harmonisation is not constrained to mean the same equipment type for the same application on the same frequency. Adoption of a harmonised compatibility model that permits diverse applications in the same spectrum space is accordingly embraced.

The Directives and Decisions which do impose boundaries of some sort are identified in the table below. The table gives information about the scope of their effect in relation to harmful interference, the requirements they impose and notes relevant to the project.

Directive	Scope	Main requirements	Notes
Authorisation Directive	Electronic communications systems / networks. Private unlicensed radio operated on a non-economic basis not covered.	Permits inclusion of conditions referencing requirements of EMC Directive for general authorisation. Conditions concerning "harmful interference" permitted only in the case of radio specific authorisations.	Applies without prejudice to R&TTED. General authorisation preferred for licence-exempt radio. Possibility of removing doubt in cases of uncertainty.
R&TTE Directive	All radio equipment with a few specific exceptions.	Restriction on "harmful interference" is applied only to radio (TTE emissions handled as EMC no matter what their nature). Invokes protection requirements of EMCD but without reference to fixed installations.	
EMC Directive	Radio equipment excluded from scope.	Protection requirements impose emission and immunity limits for electromagnetic disturbance. Additional specific requirements for fixed installations.	Protection requirements (only) called up by R&TTED.
Radio Spectrum Decision	Measures ensuring harmonised conditions for the availability and efficient use of the radio spectrum.	Provides for "technical implementing measures" defined on a case-by-case basis with a view to harmonisation.	Framework Directive directly references the Spectrum Decision.

Examination of the table and the relative attributes of the Directives and RSD leads to the following observations:

- The R&TTE Directive is the only current instrument with a scope sufficient to impose requirements on all radio equipment irrespective of its application. This does not preclude the creation of technical implementing measures under the RSD.
- The R&TTE Directive treats "harmful interference" uniformly for all radio equipment and does not envisage classes of equipment subject to different degrees of protection other than the extent to which this is permitted in the definition of "harmful interference" itself (i.e. in accordance with the applicable Community and national regulations). Technical implementing measures under the RSD would be an appropriate regulation to make such distinction at Community level and individual spectrum rights under the Authorisation Directive might be used for specific cases at national level (see next point).

- The Authorisation Directive embraces only radio equipment used in an electronic communication service or network and does not reference harmful interference in relation to radio systems operating under general authorisation. It may have some value in clarifying the applicability of electromagnetic disturbance requirements to dispersed (non-radio) electronic communications systems under general authorisation but the new EMC Directive would now seem to address this matter fully. Accordingly, the main value of the Authorisation Directive in the present context is to deal with specific rather than general matters relating to harmful interference.
- The requirements of the EMC Directive have no direct relevance and are invoked entirely under the control of the R&TTE Directive. This supports the key role of the R&TTE Directive identified in the first bullet point above.
- The RSD does not constrain the content of technical implementing measures but does strictly define the procedure for their creation by means of exclusive mandates to CEPT. This is also discussed in Section 4.4 of this report dealing with compatibility studies and related institutional matters.

5.2 Specification of Harmful Interference Parameters

The technical parameters which effectively specify harmful interference at EU level are dispersed over a number of different documents with varying degrees of mandatory force.

Harmonised standards	Not mandatory. Separate standards address electromagnetic disturbance and harmful interference. Give presumption of compliance with essential requirements.
Radio interface definitions / Interface regulations	Mandatory. Issued by NRAs based on obligations under Article 4.1 of R&TTE Directive. Format has been agreed by TCAM and includes some interference parameters (eg power limit).
Sub-classes of Equipment Class 1	Formal status is "indicative" at EU level but often afforded higher status in member states, for example, by being reproduced in whole or in part in interface regulations (see row above). Effectively, they are mandatory if Class 1 status is to be claimed with no risk of challenge. Class 1 equipment has no restrictions on putting into service in any member state[35]. The list of sub-classes is maintained by ERO.
Implementation Decisions by the European Commission under the RSD	Binding on all parties to whom the Decisions are addressed. Some current Decisions overlap sub-class definitions and interface regulations.
Authorisation (licence)	Mandatory. Should not duplicate any obligations imposed at EU level but otherwise NRAs may impose particular requirements on equipment subject to licence in order to deal with specific electromagnetic disturbance or harmful interference issues.

[35] Commission Decision 2000/299/EC of 6 April 2000 establishing the initial classification of radio equipment and telecommunications terminal equipment and associated identifiers

This situation is confusing to manufacturers and sometimes a source of frustration to regulators and manufacturers alike. The harmonised standards, which contain the most detailed elaboration of technical requirements, do not have mandatory status[36] although they are generally considered by industry to be the rule to apply. Perhaps due to a lack of confidence in this practical reality, some regulators have been perceived on occasions to be over-prescriptive in their national interface regulations, for example, by repeating elements from standards in their regulations. Commission Decisions representing technical implementing measures under the RSD have more recently provided a harmonised mechanism for dealing with the imposition of elements considered mandatory, the preferred approach being to refer to mechanisms in harmonised standards in a manner consistent with the R&TTE Directive. However, so far, this does not appear to have displaced the corresponding technical content of interface regulations.

The overlap of Commission Decisions, sub-class definitions and national interface regulations is also a source of confusion. This stems largely from the different parties and procedures relating to each of the measures which even when there is a common goal in sight can lead to conflicting requirements having force at the same time.

Another confusing factor in the case of short range devices is ERC Recommendation 70-03 which, like the sub-class definitions, is maintained and published by ERO. An earlier study[37] described 70-03 as "the principal consolidated source of information concerning SRDs in Europe" but described it as "lengthy and complex". The distinction between the formal status of the sub-class definitions and 70-03 is often lost. ERC Recommendation 70-03 is probably better known at a global level and sometimes wrongly regarded as definitive for the purpose of EU Directives by the less well informed.

The Commission Decisions taken under the RSD emerge here as the most effective vehicle for "must have" harmful interference technical parameters with complementary detail spelt out in harmonised standards. In considering an evolution towards giving greater focus to this, it should be considered that the obligation on the Member States to notify interfaces under Article 4.1 of the R&TTE Directive does not require publication of an interface regulation. Interface regulations have arisen by agreement in TCAM on practical operational measures. Similarly, the publication of indicative sub-class definitions is a practical operational matter which does not in itself impose mandatory obligations. This opens the possibility that the use of the various elements described above might be simplified and used in concert to provide optimal approaches for different kinds of spectrum policy as suggested in the table below.

[36] Whilst harmonised standards give a presumption of compliance there is the possibility of adopting other solutions provided the same level of protection is achieved. This possibility is rarely used in practice but is a useful option in some cases (errors in standards, technical innovation).

[37] Study on legal, economic & technical aspects of "collective use" of spectrum in the European Community by Mott MacDonald Ltd, Aegis Systems Limited, IDATE, Indepen Ltd and Wik Consult
http://ec.europa.eu/information_society/policy/radio_spectrum/docs/workshop_collective_use/cus_rep_fin.pdf

Policy	Commons	Market based / property rights	Command & control
Harmonised standards	Yes	Yes	Yes
NRA Interface regulations	No	Only if not possible to address in Commission Decision.	Yes
Commission Decision	Yes	If necessary (for example to control out-of-band emission).	Unlikely.

In formulating the table, it is assumed that it will not be necessary to address technical parameters for electromagnetic disturbance or harmful interference in authorisation conditions and that indicative sub-class definitions can be dispensed with entirely through judicious use of the other instruments.

The above suggestions are without prejudice to the possibility that any or all of the measures may be required for purposes other than control of technical parameters for electromagnetic disturbance or harmful interference[38]. For example, an authorisation may be necessary to specify property rights, or a Commission Decision may be used to harmonise a particular band for "command & control" regulation without further specifying technical parameters.

It is noted that the RSD and R&TTE Directive are already being used to bring some order to the current confusion, but not to the degree set out above. The Commission Decision 2005/513/EC of 11 July 2005 on short-range devices (SRD) and revisions to the sub-class definitions have been used to align matters. The Commission has advised that extension of the SRD Decision will have it replace the ERC Recommendation 70-03 by an equivalent Community instrument founded on a solid legal basis.

[38] Note that the Commission has already publicly ventilated possible proposals to be included in the Review regarding authorisations, where EC Decisions under comitology (i.e. implementing decisions under the RSD) could be taken to 1) ensure general authorisations (i.e. licence-exempt) are provided in particular bands, and 2) establish common conditions for the granting of individual spectrum rights (i.e. licences) for services with a significant cross-border dimension ("pan-European" services)

Illustration of some of the issues raised in this Section:

Harmonised use of radio spectrum in the 5 GHz frequency band for the implementation of wireless access systems including radio local area networks (WAS/RLANs) (Commission Decision 2005/513/EC amended by Commission Decision 2007/90/EC)

RSC sends Commission Mandate to CEPT	20 DEC 03
CEPT Response	12 NOV 04
RSC agreement on CEPT Response	01 JUN 05
Commission Decision in OJ	11 JUL 05
Amending Decision in OJ	12 FEB 07

Notes:

1) As at 31 August 2007 no corresponding sub-class description for the purposes of the R&TTE Directive is available from ERO.

2) In contrast, ERC Recommendation 70-03 has included the corresponding information since August 2005

3) In this instance, the Commission Decision does not modify the harmful interference considerations to "non-protected" status as it does, for example, in the case of the Commission Decision 2006/804/EC concerning UHF RFID devices: "…no claim may be made for protection of these devices against harmful interference originating from radio communications services…"

5.3 Recommendations for Implementation

5.3.1 For the Authorisation Directive

The analysis earlier in this section concluded that although the Authorisation Directive contains specific references to harmful interference, it has little potential for limiting or controlling interference in any general way. The Consultant has been unable to identify any examples within the scope of the Authorisation Directive where harmful interference constraints would not anyway be imposed on radio equipment through the R&TTE Directive. It is also observed that Directive 2004/108/EC concerning EMC now makes it abundantly clear that all fixed installations, whether or not providing communications services, must respect the protection requirements concerning electromagnetic disturbance.

However, it is noted that Article 5.1 of the Authorisation Directive references harmful interference in a manner intended to strongly promote the use of general authorisation where the risk of harmful interference is negligible. This different perspective may be adequate justification for retaining the harmful interference references but is not key in the context of this study.

It is also noted that the Authorisation Directive is itself a Community regulation in the context of the harmful interference definition (current and proposed) and can therefore be used to permit interpretation of harmful interference in the case of individual spectrum rights.

Recommendation 5.1: To maintain coherence with the other recommendations of this report, the Authorisation Directive should be amended to take account of the following:

- the definition of harmful interference proposed elsewhere in this report (section 3.4.1);
- clarification of harmful interference as a particular class of electromagnetic disturbance for which special putting-into-service and enforcement provisions are available;
- elimination of similar terms to “harmful interference” and “electromagnetic disturbance” which are not defined;
- specific references to the new EMC Directive 2004/108/EC; and
- recognition that harmful interference may arise from sources other than electronic communications systems using radio equipment.

It is understood that not all such recommendations were included in the recent Commission proposals for amendment of the Authorisation Directive, in which case the European Parliament and Council could consider following up on such ideas in their scrutiny of the Commission proposals.

5.3.2 For the R&TTE Directive

Recommendation 5.2: The R&TTE Directive should be changed[39] to accommodate the following specific points:

- the definition of harmful interference proposed earlier in this report (section 3.4.1);
- the new EMC Directive 2004/108/EC, in particular to make explicit reference to the full essential requirements for electromagnetic compatibility and the specific provisions for fixed installations;
- clarification of harmful interference as a particular class of electromagnetic disturbance for which special putting-into-service and enforcement provisions are available;
- recognition that harmful interference may arise from sources other than radio equipment;
- refocusing the essential requirement exclusive to radio equipment on efficient and appropriate use of the spectrum only;
- recognising the role of technical implementing measures under Decision No. 676/2002/EC as applicable Community legislation for the purposes of the harmful inference definition and hence a means of “fine tuning” the harmful interference definition on a case-by-case basis; and
- elimination of terms similar to “harmful interference” which are not defined.

[39] The opportunity would be the formal Review of the Directive, announced for 2008.

5.3.3 For the EMC Directive

The proposals above for the R&TTE Directive do not allow for the possibility of harmful interference from electrical or electronic equipment that is not Telecommunications Terminal Equipment (TTE) or Radio Equipment (RE) which means that enforcement action in such situations cannot proceed on the same basis as in the case of radio equipment and must be made on the basis of "electromagnetic disturbance" under the EMC Directive rather than with specific powers for harmful interference. As per recommendation 3.4, the EMC Directive should be amended to introduce the specific concept of harmful interference in order to achieve this.

5.3.4 For the specification of harmful interference technical parameters

Recommendation 5.3: Concerted efforts should be made to concentrate the specification of technical harmful interference parameters in the Commission mandated measures of Harmonised Standards under the R&TTE Directive and Technical Implementing Measures (Commission Decisions) under the Radio Spectrum Decision.

Recommendation 5.4: The use of Radio interface definitions and interface regulations, definitions of the sub-classes of Equipment Class 1 and authorisation (licence) conditions for such technical parameters should be avoided to the maximum extent possible and, in the case of licence exempt use of spectrum "commons", avoided altogether. This includes, other than by cross reference, the repetition of parameters in the mandated measure in order to avoid confusion caused by failure to keep the numerical values of all such citations "in step".

6. Technology Issues

6.1 Basic Considerations

It is a well-known fact that distribution of spectrum between interested parties is a compromise between needs and availability. If the availability could be decided without consideration of physics, the problem could be reduced to a straightforward administrative task and political decision such as for emission rights of CO_2 or driving licences. Unfortunately, neither physics nor the permanent wish of engineers to improve technology in combination with the growing requirements of our society for more uni- and bilateral communication, forces a freezing of standards. Thus we face a permanent changing mix of technologies ranging from low power short-range devices up to high power broadcast and TV stations, radar and satellite communications. And not all technologies are in use equally in all parts of the world.

In addition the propagation of radio waves is not identical to light, but range increases as frequencies become lower. It will always be necessary to consider physical effects in conjunction with any consideration of interference.

Nevertheless there are means to handle interference and optimise the use of the scarce resource. At present, licences are categorised in 3 main groups: individually licensed, block licensed and licence-exempt (or general authorisation). Each of these is described below:

- **Granting of individual licences per site.** Individual licensing is commonly used for bands where many different users are operating one or a small number of radio stations. For each of the stations a licence is granted on a one-off basis. The usage of spectrum by a radio station is constrained geographically by the licence. Avoidance of harmful interference is achieved by technical planning of the radio site. This can be done either by the regulator or the operator of the radio station. In the latter case the site has to be approved by the regulator once the operator has finished the planning. Typical examples where site licensing is used are sound and television broadcasting or radio stations for small trunked networks.

- **Licensing of entire frequency blocks.** For block licensing a set of frequencies (a frequency block) is assigned to a user (operator). Within this frequency block the operator can use as many transmitters as desired, as long as the deployed equipment is in line with the technical parameters set out in the licence conditions (e.g. a designated technical standard). It is the responsibility of the operator to plan the system in a way that harmful interference between different radio stations is avoided.

  Block licences can be limited to a specific geographic area or granted on a nationwide basis. In both cases regulatory rules have to be defined for how interference is avoided at borders of the licence regions. Examples of block licences are licences for cellular mobile networks or licences for wireless broadband access based on point-to-multipoint technology.

- **Licence exempt or general authorisation (Class or Common licensing).** Class or common licensing can be understood as a special case of block licensing. In this case a part of spectrum can be used by anyone without prior individual approval of the regulator as long as pre-defined operating rules like a defined technology and technical limits for transmit power are adhered to. Avoidance of harmful interference in band is left either to the user itself (e.g. listen before talk) or to the deployed systems (e.g. adaptive frequency selection). Examples of this include the frequency bands used for DECT and the PMR 446 systems.

Within these categories interference management is carried out very differently:

- For the individually licensed users the regulator usually conducts any spectrum or interference management necessary;
- For block-licensed users typically the operator carries out most of the interference optimisation on his own;
- Licence exempt services are often self-managed and operate on a first come-first served as well as using techniques such as negotiation between users or devices.

If we accept these categorisations, there are differing levels of promise for improvements: Licence exempt services are usually crowded into a small playground shared many different types of short range devices and therefore any room for improvement is very technology driven and will be driven by the suppliers themselves.

Within the study we have therefore focussed mainly on the block and individual licences. This does not mean a carte blanche for ineffective systems located in the licence exempt bands. The proper use of licence exempt spectrum has to be permanently monitored by the regulator. In addition, there is always the basic question of resource distribution between the parties as well as whether the general grouping has to remain identical in the future.

In order to analyse these questions in more depth and give direction for an effective future approach, this section is focussed on answering the following questions:

- What is the nature of interference?
- What are the mechanisms (current and known future) to control interference?
- What are the opportunities for improvement?

6.2 The Nature of Interference

6.2.1 Mechanisms of Interference

Radio interference can be caused by a number of different mechanisms, each with its own unique characteristics. Understanding these different interference causes is useful in defining how the various mitigation techniques work, i.e. which of the possible causes they aim to address.

There are six basic mechanisms which reduce the performance of systems by radio frequency interference:

- **Direct Interference:** Emissions on the same frequency as the wanted signal which could be due to in-band or out-of-band emissions.
- **Adjacent Channel Interference:** Emissions on frequencies directly adjacent to the wanted signal.
- **Image Frequency Interference:** Interference caused by emissions on frequencies other than the wanted frequency but which a receiver is sensitive to[40].
- **Mixing Products:** Signals appearing on the wanted frequency generated through other mechanisms. These could be caused at the transmitter or the receiver.
- **Blocking:** Interference caused when a receiver is overloaded to the point of functional failure by transmissions on neighbouring frequencies.
- **Induction or Conduction:** Interference caused by induction or conduction of unwanted RF signals into a piece of equipment.

Each interference source will typically affect the performance of a system by only one of the mechanisms identified above. It is therefore worth understanding the nature of each of them.

Direct Interference

Direct interference occurs when emissions are present on the wanted frequency, i.e. that which is trying to be received. Such interfering emissions may have a number of sources:

- **Co-Channel Transmissions:** Other stations are using the same frequency and are within geographic range of the victim receiver. Such stations could be operating within their licence conditions or may be unlicensed. (It is beyond the scope of this project to consider mitigation issues for illegal radio usage).
- **Spurious Emissions:** Stations where equipment is malfunctioning or is poorly installed or operated may emit radio signals on frequencies other than those intended. However, malfunctioning equipment is not considered further in this project since the simple remedy is to repair or replace the faulty equipment or installation.
- **Out-of-Band Emissions:** Emissions caused by equipment operating within its designed operating parameters, but which are incidental to the main emission (typically either at a harmonic or multiple of the wanted frequency or, especially for digital systems, on adjacent frequencies).

Direct interference is one of the most severe forms of interference as it has a direct impact upon the victim receiver and cannot be mitigated by any simple technological means. It also has the greatest potential to damage reception of the wanted signal to the extent that it may become unreceivable. Depending on the source of the interference, it also has the potential to affect many receivers which are tuned to the same frequency and which may be spread over a wide area.

[40] Such as the image or intermediate frequencies in superheterodyne receivers.

Adjacent Channel Interference

Radio receivers contain complex filters which attempt to ensure that only the wanted signal is received; but no filter is perfect and the imperfections in these filters mean that transmissions on neighbouring or adjacent frequencies can leak through into the receiver and cause interference to reception. The extent to which this occurs depends on the quality of the filters in the receiver, and it is this factor which tends to determine the spacing required between adjacent transmissions.

This type of interference is also sometimes referred to as 'In-Band Interference' where the emissions causing the interference are in their correct band (compare this with out-of-band emissions above).

Image Frequency Interference

Some kinds of radio receiver work by combining the incoming signal with a varying frequency in such a way that the resulting 'mixing product' is at a fixed frequency (usually called an intermediate frequency). For example, an incoming signal at a frequency of 90.7 MHz could be mixed with a frequency of 80 MHz to produce a result at 10.7 MHz (90.7 – 80). To re-tune the receiver we change only the 80 MHz frequency, to say, 81 MHz. The receiver is now tuned to 91.7 MHz (81 + 10.7). Such a technique is known as a superheterodyne receiver and has two image frequencies, one at the intermediate frequency itself (in this case 10.7 MHz – a common choice) and a second at the frequency corresponding to the other mix – in the examples above these are 69.3 and 70.3 MHz (80 – 10.7 and 81 – 10.7) respectively.

Image frequency interference therefore occurs if emissions are present on these alternative frequencies on which the receiver is sensitive. A complex set of filters in the receiver will attempt to reduce sensitivity as far as possible to such problems; however if the interfering signal is strong enough problems will still occur.

This type of interference is clearly a function of the receiver which will respond to any of the other interference mechanisms identified and as such is a distinct form of interference per-se.

Mixing Products

Just as receivers mix two signals to produce a third, the same phenomena can occur in an unwanted fashion, either at the transmitter or receiver and result in interference. Thus two transmitters operating at frequencies of f_1 and f_2 have the potential to produce emissions on frequencies of $f_1 + f_2$, $f_1 - f_2$ and other combinations such as $2f_1 - f_2$ and $2f_2 - f_1$. All these products are known as mixing products and are the result of non-linearities either in the transmitter(s) or in the receiver. Typically, at any given transmitter site, frequencies are chosen so as to try and ensure that any such products do not fall within the range of frequencies which are trying to be received, however this cannot always be done for mobile receivers which are subject to many different frequencies as they move around.

Due to the nature of mixing products, especially for mobile stations, it can be very difficult to predict their presence.

Blocking

If a receiver is placed in a very strong radio frequency field (which could be caused by one or more transmitters), the receiver can become overloaded and may be unable to receive wanted frequencies correctly, or at all – the receiver is then said to be 'blocked'. This is more often a problem if the overloading signal is similar in frequency to the wanted signal as any filters which may be present in the receiver to attempt to stop such blocking are less effective.

Blocking can be severe, especially in cases where the wanted signal is particularly weak and neighbouring transmissions are particularly strong, or where the receiver is poorly designed or has been designed to a very low budget. Whilst developments in RF technology have improved receiver dynamic range[41] which has a direct impact on the likelihood of blocking, it is still a significant problem.

Induction or Conduction

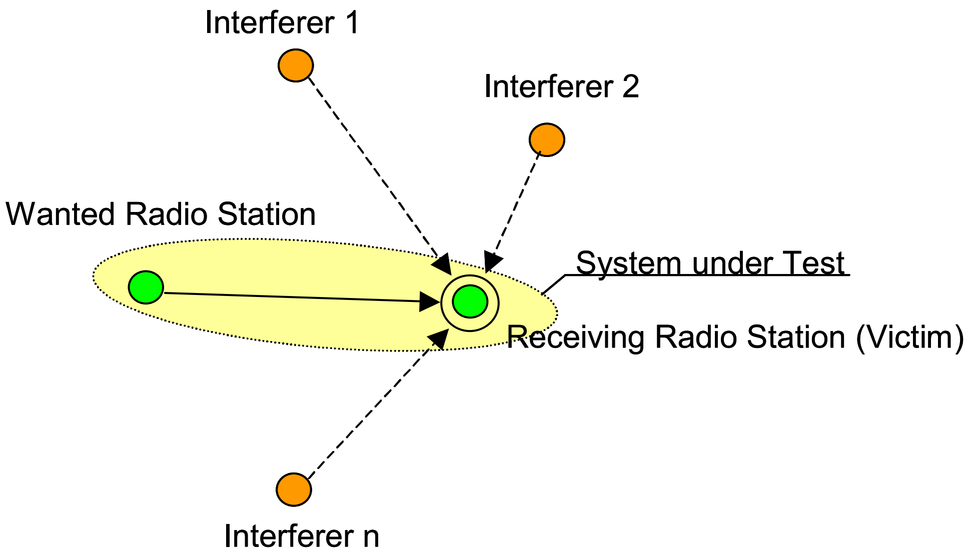
Strong RF fields will induce a current into any antenna and any length of conducting material will act as an antenna. The induced current can then enter equipment and can interrupt the operation of the equipment (the buzzing heard when a mobile phone is held near an audio device such as a CD player is typical of this type of problem). Very strong RF fields are necessary to cause this effect so that this type of interference tends only to occur in the direct vicinity of transmitters, with higher power transmitters giving rise to a more pronounced effect.

This is less of an issue for interference between radio systems, but a major cause of interference from radio transmitters into non-radio products. The EMC directive exists to attempt to provide immunity to interference through induction and conduction.

6.2.2 Technical Description of Interference

To describe interference from a technical point of view a set of parameters has to be defined. These are illustrated in the following diagram which shows a generic interference situation:

[41] The dynamic range of a receiver is the range of signals which can be safely received. Poor receivers may exhibit a dynamic range of, say, 90dB meaning that the weakest signal that can be received is 10^9 times smaller than the largest. A better receiver may have a dynamic range of 120dB and thus can cope with a range of signal strengths 1000 times greater.



To model the interference situation the following technical parameters and methods have to be defined:

- the system under test including;
    - wanted radio station with characteristics,
    - characteristics of transmitted signal.
    - receiving radio station with characteristics,
    - characteristics of propagation path between wanted and receiving radio station (usually worst case)
- for each of the interfering radio stations (interferer) the
    - characteristics of the interfering radio station,
    - characteristics of the transmitted interfering signal,
    - characteristics of the propagation path between interferer and receiving radio station (victim) (usually best case)
- For both the interferers and the system under test there are scenarios of defined locations (sites) as well as defined areas. If an area is defined, it has to state how test scenarios have to be generated. This may be extreme locations or a statistical approach with e.g. a Monte Carlo distribution of the possible interferer locations.
- Method to aggregate interfering power in case of several interferers

Methods to calculate interference by using such methods are found in annex F.

6.3 Approaches for Controlling Interference

Of the various interference types defined, only three could be controlled through spectrum or interference management procedures, the rest are too sporadic in their formation, or are caused by factors other than those related directly to any controllable factor (such as proximity of a user to a transmitter) to be able to be managed through control over the devices. The interference types that we need to consider are therefore:

- Direct Interference;
- Adjacent Channel Interference; and
- Blocking.

To determine the effects of direct interference we need to establish the amount of interfering signal which is present at the victim receiver's input. This can change due to a variety of factors, some which can be set at the transmitter, and some which can be, to some extent, controlled at the receiver. The level of interfering signal then needs to be compared to that of the wanted signal (and local noise level). Finally, the victim system's susceptibility to interference must be determined. Together we can then determine the impact on the system.

Determining the effects of adjacent channel (or 'in-band') interference is a similar process to that for direct interference, although the victim receiver's adjacent channel filter characteristics also need to be taken into account.

Blocking is a much more complex problem to analyse. It is not necessarily the ratio of wanted to unwanted signal that must be maintained (taking into account receiver filter characteristics) but instead the absolute level of the unwanted signal relative to the receiver's dynamic range, filter characteristics and other factors. As such, determining when blocking will be caused is difficult; however when there is a very strong signal on a frequency close to the wanted signal the chance of blocking exists. In the coming sections we will focus on the ways to control, reduce or avoid the indicated interference sources.

6.3.1 Administrative Approaches for Controlling Interference

Radio interference occurs at a receiver when the reception of the wanted signal is hindered by one or more unwanted signals that are received simultaneously with the wanted signal. Thus for interference regulation it is necessary to have at least a minimal set of technical parameters and methods to describe and analyse the interference situation:

- Technical description (set of parameters) for the interfering and victim systems;
- Information regarding the locations of the radio stations involved; and
- Assumptions regarding possible ways of interaction/interference between the systems (Wave propagation and technical interference model).

Whilst for systems with a relatively small number of radio stations, interference analysis can be done with limited computational effort, for larger systems the effort will become very significant. Thus in the past it has often been practical considerations, rather than technical requirements, that have been the underlying principle of regulatory measures for interference avoidance. The most practical way to avoid dealing with an extensive set of precise technical details for various services and systems has been very often to assume general, homogenous characteristics for similar services. Based on such a generalised service approach a licence-centric system of spectrum management has evolved that is currently found in most countries.

Organisational Measures – Licensing

A common approach applied by national regulators to avoid harmful interference is more organisational than technical; the applied approach is in most cases to control and limit the access to the radio spectrum. A typical means of achieving this is by granting licences to users. In most cases a potential user has to prove that they are eligible to operate the service in a proper way before they are awarded a licence.

To comply with international regulations and to avoid cross border interference the licences have to fit into the international band plans. Thus the overall procedure of licensing can be described as follows:

1. The radio spectrum is divided into bands by the national regulator while taking into account international constraints like the Radio Regulations published by the ITU.

2. The bands will be allocated to different types of usage or services once again in accordance with the international agreements.

3. To avoid interference between systems operated in adjacent bands, guard bands between the adjacent bands are determined by analyzing the technical parameters of the intended services.

4. Where different services or systems are to be operated in the same band the technical limitations of such a shared use are determined by means of compatibility studies.

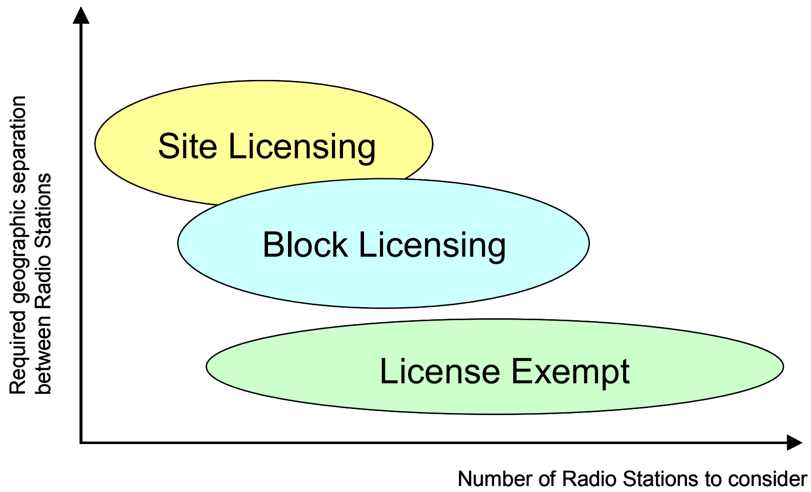
5. For each band the licence type has to be determined.(licence types are discussed in section 6.1).

6. Finally, licences are granted to spectrum users; the correct usage of spectrum will be enforced by means of spectrum monitoring

As discussed in section 6.1, the primary licence types are:

- Licensing of entire frequency blocks.
- Granting of individual licences per site.
- Licence exempt or general authorisation (Class or Common licensing).

Whilst in general each of the above licensing methods can be applied to each service, for practical reasons (for example the effort required for technical checks during licensing), not all types of licence are used for all types of service. A rough differentiation can be found based of the number of radio stations that should be included in technical checks and the required separation between radio stations to allow interference free operation while using the same channel:



Please refer to Annex F for technical aspects of regulating interference by licensing.

6.3.2 Recent Regulatory Approaches for Interference Management

Besides technological measures to reduce interference that operates on a physical level, adaptive approaches that work on an inter-system level have also been discussed in recent years. Below are two such examples.

Interference Temperature - FCC

This FCC approach for managing the radio spectrum and controlling interference aims to improve the efficiency of spectrum usage[42]. The resulting additional resources should be used to create opportunities for new communication services and obtain public benefits.

Contrary to many current models, which use statistical parameters for assessment of the interference situation, the interference temperature procedure tries to describe the real situation: the influence of transmitters, receivers and mutual interactions are considered. To estimate the actual interference conditions the model uses real-time measurements of the spectrum, therefore to get the required information a monitoring network must be established using special measurement receivers which send the measured interference temperature to a central point.

[42] *"Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Band s"* ET Docket No. 03-237; FCC

With the received data the responsible transmitters can adapt to the interference situation and a compromise between effective usage of the spectrum resources and interference temperature can be reached. If, for example, the interference temperature is not reached, the power of some transmitters can be increased. This will allow for a more flexible system design. The evaluation of the actual interference is done by measuring the increase of the noise floor caused by the interfering RF signal. The estimated interference levels are adjusted by an additional margin to compensate for external interference. The model recommends temperature limits that are used to determine a maximum interference level in a frequency band. Any adjustment in a network will be limited to these values.

In comparison to other interference models this model allows for the inclusion of real time measurements of the actual interference level. However, as only single, local values are used to determine the interference level for the area around a measuring receiver, an extrapolation has to be done to determine the interference temperature in areas not covered (or between) the measurement receivers. This critical extrapolation is a source of error and must be done very carefully as the risk of producing harmful interference can increase in an area where no measurements have been taken or no measurement receiver established.

To provide a good and functional measurement network a high number of measurement receivers are necessary. This will increase the cost for the implementation of such an interference management model. In addition, the ability of transmitters to dynamically adapt to commanded requirements to fulfil the interference temperature limitations, will lead to an increased effort and requires central management units. Rising costs are connected with an increase in flexibility.

On May 2, 2007 the FCC terminated the proceedings without introducing the interference temperature method with the following statement:[43]

> Commenting parties generally argued that the interference temperature approach is not a workable concept and would result in increased interference in the frequency bands where it would be used. While there was some support in the record for adopting an interference temperature approach, no parties provided information on specific technical rules that we could adopt to implement it. Further, with the passage of time, the Notice and the record in this proceeding have become outdated. We are therefore terminating this proceeding without prejudice to its substantive merits.

Spectrum Usage Rights - Ofcom

Whilst considering the necessary factors to implement spectrum trading, the UK regulator Ofcom began considering how the rights of spectrum licensees might be described. The result of this consideration was the concept of spectrum usage rights, the spectrum equivalent of property rights. Spectrum usage rights define the asset which can then be traded under the spectrum trading legislation.

[43] Order to FCC Docket 2-237, May 2, 2007

A typical existing licence might define a frequency of operation, the location of the transmitter, the maximum radiated power (and any directional restrictions) together with a specification for the equipment type being used which would then define the characteristics of the transmission in terms of the interference it could potentially generate. This defines the 'cause' of interference, Ofcom realised that such a licence would have a low tradeable value as the likelihood of a user wishing to have access to a single transmitter at a pre-specified location was small. Ofcom therefore considered the 'effect' of the interference. Instead of defining the licence in terms of transmitters, powers and so forth, it defined a transmitter mask which defined only the in- and out-of-band interference levels that were permitted, together with the area over which the licence was valid. This loosening of licence parameters allows any potential trader to change the technology used as part of the licence, as well as, potentially the transmitter site or sites, powers, antennas and so forth. From a regulatory perspective, it would still be possible to connect equipment to the transmitter(s) and to measure the transmitter parameters and determine whether or not a particular station was within its licensed parameters.

As a further step, Ofcom has considered the use of power flux densities to measure the interference generated by a network of stations, instead of direct measurements at each transmitter. In such a situation, the spectrum usage rights would be defined in terms of the maximum power flux density (PFD) levels of in- and out-of-band interference that a licensee would be allowed to generate (and conversely which a licensee might expect to receive in their spectrum).

The concept of spectrum usage rights was generally warmly received when circulated for consultation by Ofcom, with users recognising that an interference-based approach offered greater flexibility, although the use of PFDs is more troublesome. There are a number of difficulties associated with the use of PFDs, most notably the fact that the interference produced (and received) is generated by a network of transmitters rather than by a single source. As such, the combinatory effect of the stations in the network must be taken into account. This can either be done through measurement or modelling, although neither method is necessarily straightforward, nor accurate. Modelling is inherently uncertain and measurements are subject to identifying suitable measurement sites. Furthermore, it is virtually impossible to take measurements of interference in a specific band whilst a service is operating in that band.

Much of the above points towards the consideration of a technology-neutral spectrum mask and this is discussed below.

6.3.3 Technical Approaches to Mitigate Interference

Several technical approaches have been discussed over the years that allow decreasing interference by using adaptive methods while accessing the spectrum. These approaches are mainly used for systems where a frequency band is accessed by a large number of similar devices.

They can be separated into different scenarios which can either be deployed on the transmitting or the receiving end of a radio communication link:

- Methods to reduce interference caused by a system;
- Methods to reduce interference caused to system originating from other systems; and
- Methods to improve system performance in interfered environments

The following table lists a set of technical approaches and indicates the benefits of the methods regarding interference control:

	Reduce Interference caused by system	Reduce Interference suffered from other systems	Improve system performance in interfered environments
Listen before Talk	x		
Adaptive Frequency Agility	x		
Automatic Power Control	x		
Adaptive Antennas	x	x	x
MIMO Technology			x
Frequency Hopping	x	x	x
Spread Spectrum Technology	x	x	x
Cognitive Radio	x	x	x

A short description of the above technologies is given in the following sections.

Listen before talk (LBT)

In this technique the transmitter monitors the radio channel for transmissions before the transmission starts. Thus this technique is sometimes also called listen before transmit. By using LBT the risk of causing interference to already operating radio stations in the band can be reduced. LBT is used in technologies like the DECT system.

Adaptive frequency agility (AFA)

Adaptive frequency agility is a method to avoid transmission in already occupied channels. For this the receiver periodically scans the radio environment and notes occupied channels. The collected information regarding channel occupation is then used to determine the transmit frequency to avoid interference to systems already in operation. AFA can be useful when frequency bands are shared among large groups of users or with another service on a secondary basis. By monitoring the activities of the primary service inside the band, interference to this primary service can be avoided. AFA can be combined with LTB and then is sometimes called dynamic frequency selection (DFS). DFS has for example been used to deploy co-existence in the 863 – 870 MHz band.

Automatic Power Control (APC)

The principle of APC is to control the used transmit power in a way that the radiated power is minimised while the required link quality is maintained. As a result the total radiated power is minimised which will in turn also reduce the probability of interference. To employ APC a feedback link between the receiver and the transmitter is required to exchange information regarding the link quality. Power Control is implemented for example in cellular mobile networks (e.g. GMS, UMTS, CDMA 2000) but also in microwave links and wireless LAN technologies.

Smart Antennas / Adaptive Antennas

Directive Antennas are used to reduce interference by directing the radiated power directly to the location of the receiver while minimizing radiation to other areas. Typical applications for directive antennas are for example satellite feeder links or microwave links. In mobile networks directive antennas are used to concentrate the transmitted power into the targeted coverage areas (cell area) to improve coverage and minimize interference.

With smart antennas a further improvement of this method is achieved. Smart antennas use signal processing in combination with antenna arrays to adjust the antenna pattern to the current situation. Thus on the transmitting side the antenna can be automatically adjusted to point towards the receiver, even if the receiver is moving. On the receiving side the smart antenna technology can be used to maximize the power received from the transmitter, in combination with APC, which allows transmit power to be reduced. In addition smart antennas can be used to discriminate among interferers.

Smart antennas are used for example in user equipment for WiMax Networks. A further example is the upcoming TD-SCDMA standard where adaptive antennas will be used as means for multiple access schemes in combination with Code Division Multiple Access.

MIMO Technology

The Multiple Input Multiple Output approach (MIMO) uses several antennas at both the transmitting and the receiving end, making MIMO an extension of smart antenna technology. The signals at receive and transmit antennas will be combined in a way that the quality of the communication or the data rate for each MIMO user can be improved. Compared to a system without MIMO technology a better usage of spectrum will be achieved. In most applications MIMO algorithms are used to increase data-rate, but MIMO also can be used to improve communication in interfered environments.

Frequency Hopping

Frequency Hopping is a method where the operational RF-frequency changes over time following a pseudo random frequency list. Depending on the speed with which the operational frequency is changed two general types of frequency hopping systems can be defined:

- **Slow Frequency Hopping (SFH)** In systems that apply slow frequency hopping the operational frequency is changed after a given number of symbols have been transmitted. Typically SFH is implemented in TDMA systems like GSM, where the transmit frequency changes for each radio frame.

- **Fast Frequency Hopping (FFH)** In FFH systems the operating frequency changes many times per symbol rather than only once per radio frame. Therefore a symbol is transmitted over a large spectrum, thus fast frequency hopping is used for example in spread spectrum applications for military usage.

In both cases frequency hopping provides interference diversity and interference mitigation from and to conventional non-hopping systems because particular channels are only in service for a short period of time before the frequency is changed. Frequency hopping also improves propagation over Raleigh faded channels which allows operation with smaller transmit powers.

Spread Spectrum Technology

Spread spectrum techniques use much more bandwidth than the minimum that would otherwise be necessary to transmit a given signal. By spreading the signal over a wider bandwidth they achieve a high immunity to narrowband interference.

Direct sequence spread spectrum (DSSS) is the most widely used type of spread spectrum systems. The spreading is achieved by applying a digital modulation scheme with spreading codes to a narrowband signal. Thus the power of the original narrowband signal is spread over a much broader bandwidth, and a very low power level is found at a specific frequency. During reception of a spread spectrum, narrow band interferers are suppressed by the so-called spreading gain.

These features allow the operation of a spread spectrum system in the presence of narrow band systems with a low risk of interfering or suffering from interference. If different spreading codes are used it is possible to operate several spread spectrum systems in the same frequency band. However as this will also increase the RF-Power in the band, interference to narrowband systems operating in the same frequency band will increase and will limit sharing possibilities. This is especially the case for cellular systems like UMTS and CDMA-2000 that make use of spread spectrum technology to achieve multiple access.

Cognitive Radio

Cognitive radio is a concept that evolves the principle of software-defined radio. A software-defined radio models fundamental components of the radio part, like modulation schemes or frequency band by programmable hardware. So changing the software or parameters of the software can facilitate a switchover between different wireless communication protocols or applications.

In software-defined radios, the change between different parameter sets has to be initiated by the user while a cognitive radio will decide by itself on the best parameter set to be used for a particular type of communication. This decision will be based on information about the current radio environment, which can be achieved by measurements performed by the radio itself or by information exchanged between different cognitive radios.

A so-called "full cognitive radio" will be able to include all available information while "spectrum-sensitive cognitive radio" will focus on the usage of the radio spectrum. In both cases interference control can be achieved. In the simpler case of a "Spectrum sensitive cognitive radio" transmission will be limited to a part of the spectrum where no or limited interference will be suffered or caused.

6.4 Fields for Improvement

6.4.1 Introduction

Technology permits the use the electromagnetic spectrum for communications. We use transmitter and receiver technology to transmit and receive radio waves. Spectrum management aims to define a framework to support an effective, harmful interference free and equitable use of the part of electromagnetic spectrum that can be used for radio communications. Thus interference management will always have to deal with technology as long as technology is used to access spectrum. So the question is not if interference management can be technology independent, but to what extent it is necessary to refer to particular technologies while defining the interference management rules.

It is the nature of such a study that not all possible and imaginable methods for improvement of the interference management may be analysed in exhaustively. Based on the time and financial resources available it is nevertheless useful to focus on the fields which appear to serve most promising results as well as where the current discussion is most fixed towards. For that reason and without any pretext that every possibility has been addressed,, we have concentrated our own investigations on the following subjects:

- **Technology neutral spectrum masks.** This approach appears across all recent discussions and would appear to be very promising as it could be a means for much easier distribution of spectrum blocks and allow for nearly arbitrary use within the blocks. It was our aim to investigate, whether such masks could be a solution.

- **Imposition of tighter receiver parameters.** It is undisputed that interference occurs at the receiver, not at the transmitter end. It is fair to say that, if technology had not progressed beyond the use of a crystal detector we would now be faced with an interference epidemic, therefore receiver design represents at least part of the solution. The parameters of receivers are often defined for a specific technology or service by a trade-off between the current technical state of the art and the costs which the market may accept. As these standards are often not adapted during the life cycle of a technology (e.g. the analogue TV receiver standards have been in place since 1961), a significant opportunity for improvements is not being realised. We have investigated some current examples in depth.

- **Spectrum Sharing.** Spectrum sharing between different services and operators may occur along geographic borders, or between users within one region and band. The need for co-ordination results in inefficient spectrum use. The reason is, that for the sake of fast and easy decision making the rules have to be simple and reproducible. During the past decade a much effort has been expended to improve the mechanics of co-ordination, nevertheless, it is still a fact that further modification of methods and/or modified approaches could lead to significant spectrum gains. Based on our investigations a loss of efficiency of between 30% to 50% of the theoretical possible figure is currently being experienced.

The above scenarios have been analysed both on a technological as well as an economic basis and the results are presented in the following sections.

6.4.2 Technology Neutral Spectrum Mask

Spectrum masks are one way in which transmitter emissions and interference are currently controlled. A spectrum mask details the level of emissions that are allowed both inside the directly licensed frequencies and in neighbouring frequencies. One initial way that a liberalised approach could be taken would be to define a technology neutral spectrum mask, that is to say a mask for transmitters (with potential implications for receivers too) that is not specific to any particular technology but which allows a number of technologies to use the spectrum whilst remaining within the same mask.

The definition of transmit or receive rights requires the control of out of band emissions. This is typically done by the means of spectrum masks that are defined in technology standards. To allow for a technology-independent definition of permissible out-of-band emissions technology-independent spectrum masks have to be defined.

In the following, an example for different masks is shown for the UMTS system. The UMTS system offers two duplex modes and a choice of different chiprates: Frequency division duplex (FDD) with a chip rate of 3.84 MChip/s and a time division duplex mode (TDD) with chiprates of 1.28 MChip/s, 3.84 MChip/s and 7.68 MChip/s are standardized. It has been found that different spectrum masks apply for base stations (BS) and user equipment (UE) in both TDD and FDD mode. Spectrum masks also vary according to the chiprate used in case of TDD mode and the power class of the base Stations[44]. The following pictures illustrate the spectrum masks:

[44] The used standard documents are: FDD Mode: BS: 3GPP TS 25.104 V3.14.0 (2007-03); UE: 3GPP TS 25.101 V7.7.0 (2007-03), and TDD Mode: BS: 3GPP TS 25.105 V7.5.0 (2007-03); UE 3GPP TS 25.102 V7.6.0 (2007-03)

Illustration of spectrum masks for UMTS base stations:

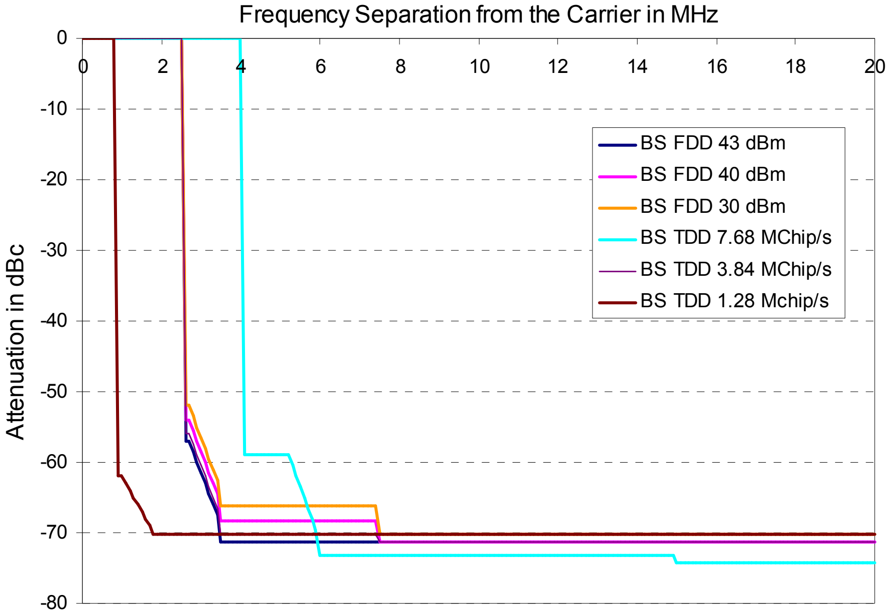
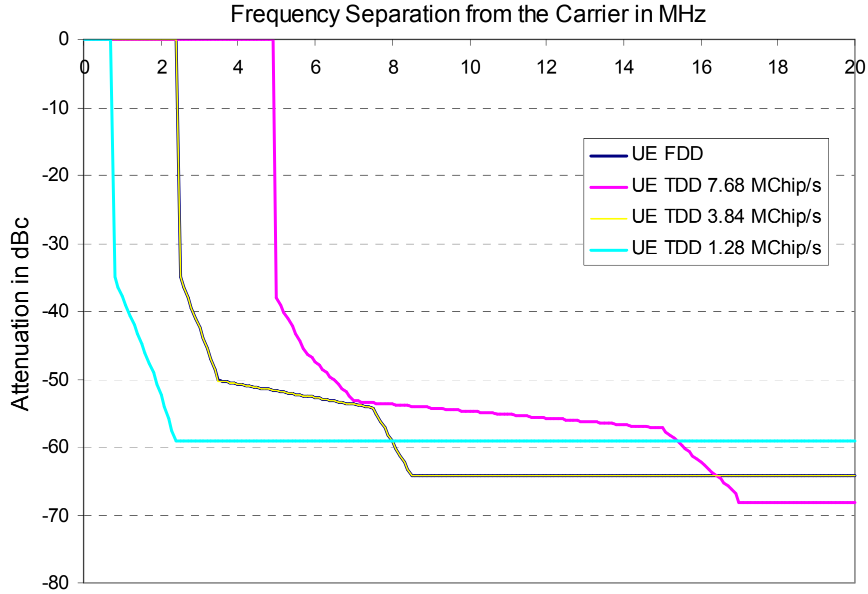


Illustration of spectrum masks for UMTS user equipment:



When comparing the masks for the base station and the user equipment it can be seen that the masks for the user equipment are less stringent than the ones for the base station which might be a concession to the smaller transmit powers used at the handsets and will lead to simpler filter designs and with this to cheaper and smaller mobile terminals.

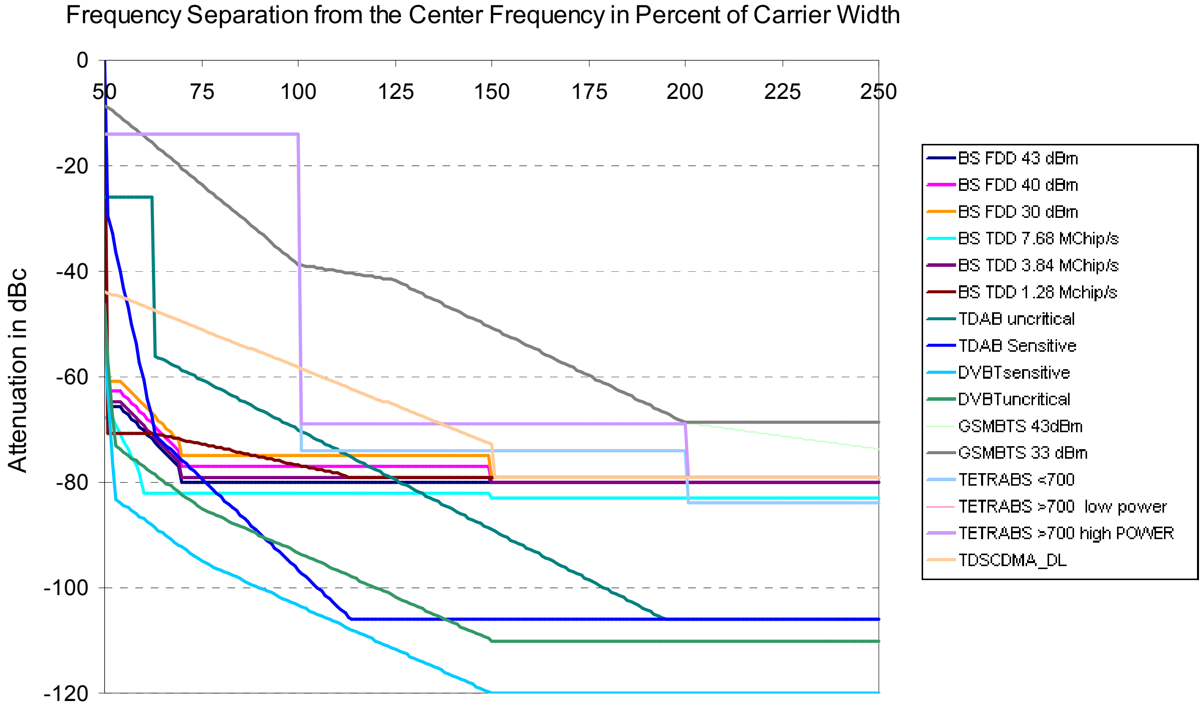
There also appears to be a disparity in the levels of ultimate spurious emissions allowed, with the case for the 7.68 MChip/s standard showing levels reaching almost 10dB lower than the 1.28 MChip/s levels. This is, in part, due to the way in which the main carrier power is spread across the in-band spectrum, but serves to highlight the care that must be taken in considering such masks and the spurious emission limits set in various standards and specifications.

Masks differ inside one standard and an even more complicated situation is found when comparing masks for different systems. Clearly different carrier widths that range from a few kHz to several MHz are used. However, the measurement bandwidth that is used to define the masks also varies in a wide range. The table below gives the values found for the standards that have been included in the analysis:

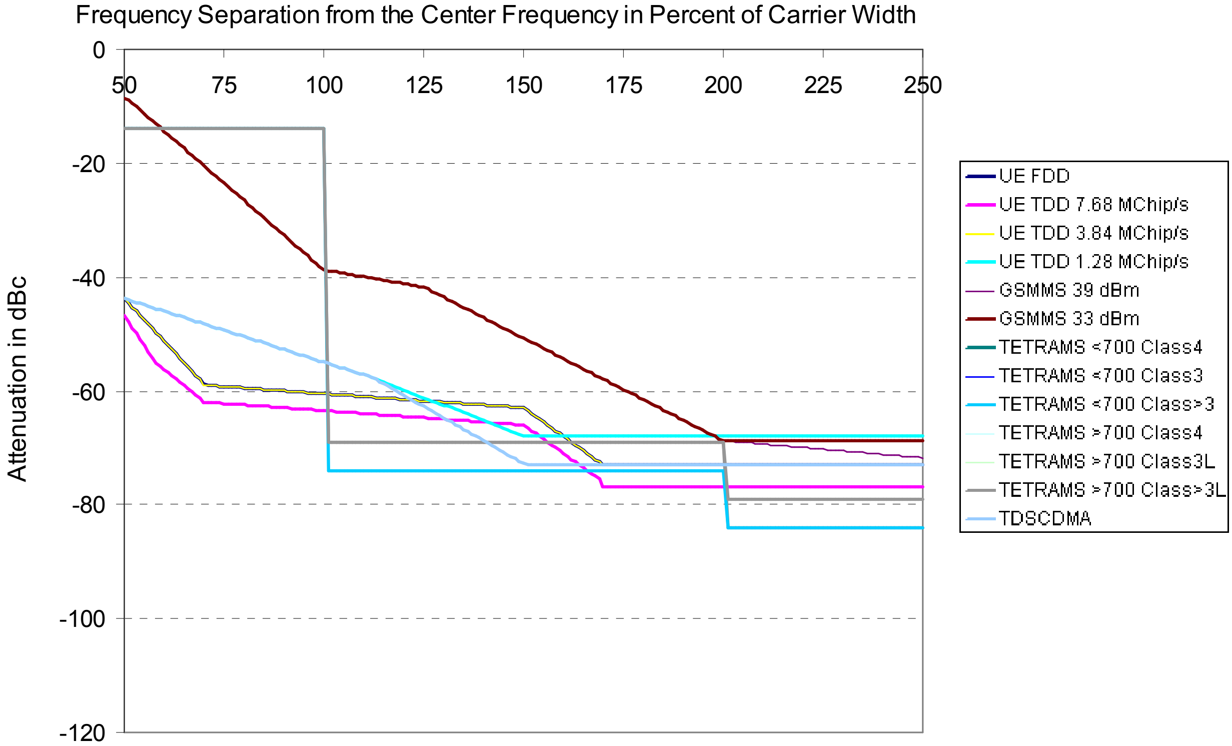
System	Carrier Bandwidth	Measurement bandwidth
UMTS FDD	5 MHz	30 kHz / 1 MHz
UMTS TDD	1.6, 5, 10 MHz	30 kHz / 1 MHz
TETRA	25 kHz	100 kHz
GSM	200 kHz	30 kHz / 100 kHz
TD-SCDMA	1.6 MHz	30 kHz / 1 MHz
DVB-T	8 MHz	4 kHz
T-DAB	1.54 MHz	4 kHz

To allow a comparison the definition of the masks has been adjusted to a common measurement bandwidth of 4 kHz. In the following charts the results are drawn over a frequency axis that shows the frequency offset from the centre frequency in percentage of the carrier bandwidth:

<u>Spectrum masks for downlink systems:</u>



Spectrum masks in uplink systems



The graphs clearly show that large variations are found between the different spectrum masks. The less stringent masks in downlink are found for the narrowband systems GSM and TETRA while the DVB-T mask for critical scenarios gives the most stringent mask for downlink systems. If it is assumed that the masks for the different systems are a compromise between technical feasibility and economic aspects, it seems unlikely that a single mask will be found that offers both good suppression of out-of-band emissions and economic feasibility.

Summary

Based on the examples as analysed above it can easily be seen that there is little possibility for defining a technology neutral spectrum mask for all services. Only in specific cases might it be feasible to set up such a “one size fits all” mask. This may be if we think of services with similar characteristics in terms of band use and cell size. We will have to ask ourselves what is the real advantage of so doing? Such a mask can allow for a user in a band to better know their limits and try coping with them, independently of the technology they wish to use. On this basis it might bring improvements especially for individual owners of a frequency block. On the other hand it will limit the frequency neighbours as well as the licensed user in their abilities and thus potentially make the spectrum use less effective. The main question will be whether the primary objective should be ease of spectrum allocation and flexibility of use which can be realised with such masks if the price paid is less effective use of Spectrum and therefore denying more users access to spectrum.

Recommendation 6.1: Technology neutral spectrum masks could be successfully used to define basic spectrum access parameters especially for block licences. Such a mask should be adapted regularly to take into account new technological advances. Beyond this a much more sophisticated method of interference optimisation would provide greater possibility of spectrum efficiency.

6.4.3 The Imposition of Tighter Receiver Characteristics

Introduction

The task of a communication system is to transmit a given amount of information within a limited time from the transmitter to the receiver. Signal degradation may occur while the signal is travelling towards the receiver through propagation effects and at the receiver itself by reception of reflections of the wanted signal and one or more unwanted signals. Interference management in the scope of this project deals with the control of unwanted signals. As the receiver design plays a key role in the suppression of unwanted signals, a possible method to manage interference would be to impose receiver characteristics that will increase the immunity of receivers to unwanted signals.

Indeed, it has been argued[45] that 'Interference is always caused by an inadequate receiver and could be fixed by a "good-enough" receiver (though "good-enough" for some situations might require adaptive antennas to null out interference, or other complex/expensive tools). Therefore, using better receivers would decrease interference, and/or allow more signals to be transmitted before interference occurred.' and that 'The goal of spectrum design is to make the world safe for cheaper receivers'.

Receiver immunity can be improved by methods such as higher performance filters, better shielding of sensitive high-gain sections or introduction of improved signal processing algorithms. Not all of these methods can necessarily be achieved by isolated modifications at the receiving end but would sometimes require a re-design of the complete communication system, including parameters and methods at the transmitter. An example of this is the introduction of a higher processing gain in a CDMA system, which will increase interference immunity but would require either a reduction in user data rate or an increase in the chip rate, both of which will impact on the transmitter. A similar case would be the introduction of improved error coding schemes that have to be implemented at both ends of the transmission chain.

The tightening of receiver characteristics is limited by technical and economic factors. A few receiver architectures can offer dependable communication at low cost, if proper design procedures and trade-offs are implemented. RF amplifiers, mixers, and filters are common circuit building blocks for all receiver architectures. System performance depends on each individual block comprising the receiver. Different targets for receiver design like linearity and high sensitivity may contradict each other. A low-noise system design typically does not produce the best linearity, and high linearity typically produces more noise so a compromise has to be found[46].

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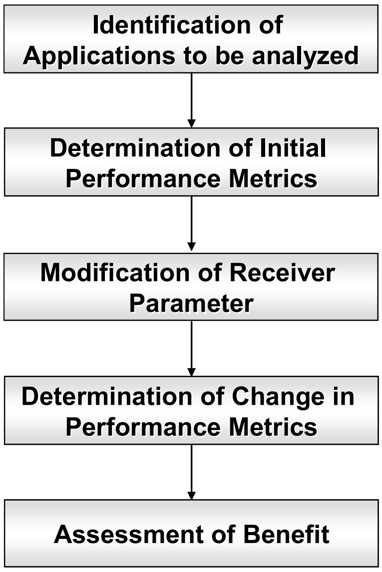
[45] "Modern Spectrum Management Alternatives", Robert J. Matheson, NTIA, 2004.

[46] "Understanding and Enhancing Sensitivity in Receivers for Wireless Applications", Technical Brief SWRA030, Texas Instruments

It is clear that, from a theoretical point of view, tighter receiver characteristics will lead to a better use of the spectrum. However the key question is whether a technically and financially reasonable solution will lead to significant improvements in spectrum efficiency.

To estimate the resulting technical and economic benefits of imposing improved receiver characteristics different scenarios have been studied. The following flow-chart shows the sequence of steps that have been taken:



To identify suitable scenarios in a first step the European frequency allocation table[47] has been analyzed to identify scenarios where either a rather large amount of spectrum is occupied by a single application or where benefits for a large number of users could be assumed (see Annex G.1 for Details). In addition, focus has been set to select environments that differ in regulatory and technical details as well as in the manner that the spectrum usage is related to economic revenue for the operators of the service. As a result the following scenarios have been selected:

1. Digital cellular mobile - 3G
2. Digital cellular mobile - GSM
3. Digital fixed radio systems - Microwave
4. Digital TV Broadcasting Networks - DVB-T.

As the performance metric, the capacity for typical system installations before and after the change of receiver parameters has be used. The changes in capacity have been transformed into bandwidth requirements. By determining the economic value of a given amount of spectrum it was possible for the economic benefit of the measures under consideration to be assessed and compared to the estimated costs.

[47] http://www.efis.dk

The results of the analyses are found in the following sections. For an overview on the economic approach used and a detailed technical description please refer to Annex G.

Case Study 1: Digital Cellular Mobile – 3G

Interference in UMTS networks directly reduces network capacity, so that an improvement in receiver performance in interference environments would be of great interest to the UMTS network operators and system vendors. Improved receiver designs have been studied and analyzed over recent years. Two such studies performed by the Technical Specification Group Radio Access Network of 3GPP, the standardization body for UMTS, have addressed methods of increasing network capacity by using interference cancellation technologies at the mobile receiver:

- Feasibility study on the mitigation of the effect of the Common Pilot Channel (CPICH) interference at the User Equipment[48]; and
- Feasibility study on interference cancellation for UTRA FDD User Equipment[49].

An analysis of these studies indicates that a capacity increase of 10% to 20% due to interference mitigation techniques is reasonable. In the frequency bands below 2500 MHz identified by WARC-92 for IMT2000 there are 2x60 MHz (in the bands 1920-1980 MHz (for uplink) and 2110-2170 MHz (for downlink)) reserved for UMTS FDD[50]. By improving terminal performance as described, the achievable capacity increase of 10% to 20% corresponds to one or two frequency blocks of 2x5 MHz paired spectrum. The technical analysis shows that there is a practical difficulty in recovering the spectrum from the operators to whom it is allocated, or in charging existing operators more - nevertheless improvement of receiver characteristics along the lines proposed would clearly improve the potential capacity of the UMTS FDD bands for any given density of base stations.

To estimate the value of the capacity thus released we analysed the amounts paid by operators in licence fees during the 3G licensing in the period 2000-2003. Although there was a large variation in the amounts paid for licences between countries, varying more than relative population and bandwidth-on-offer would suggest, an industry average can be calculated. It is worth noting that in some countries (e.g. Sweden and Finland) emphasis was placed on service and coverage rather than government revenues. Another source of licence payment differences was the telecom sector crash of 2001 which came in the middle of the process and was to a considerable extent brought on by the very process itself which had resulted in such high licence fee bids in the UK and Germany. But it is also worth noting that the bidding took place well before commercial network equipment and terminals were available. Now that they are available, and commercial services have been established, the value of additional spectrum or capacity without the need to increase the number of base stations would arguably be considerably higher than the estimates of 4-7 years ago, with all their attendant uncertainties.

[48] "*Feasibility study on the mitigation of the effect of the Common Pilot Channel (CPICH) interference at the User Equipment (Release 5)*" 3GPP TR 25.991 V5.1.0, 12.2002

[49] "*Feasibility study on interference cancellation for UTRA FDD User Equipment (UE) (Release 7)*" 3GPP TR 25.963 V7.0.0, 04.2007

[50] http://www.umtsworld.com/technology/frequencies.htm

Bearing in mind these caveats, the results of the analysis are as follows:

Case Study 1: 3G Networks - Improved Interference mitigation at user terminal			
			Notes
Assume applies to whole of EC population - million	494		
Benefit each way FDD MHz	Lower Case	5	MHz
	Higher Case	10	
Imputed value from average Licence Fee - whole of EU - €m	Lower Case	6,203	Licence Fee Value only - other benefits would add to this figure
	Higher Case	12,405	
Assumed 3G penetration at time of introduction		25%	
Estimated Number of 3G terminals to be modified		124	Million
Breakeven additional cost per terminal € at replacement	Lower Case	50.20	
	Higher Case	100.40	

We believe this analysis to be very conservative. While the estimate of how much spectrum can be freed at the technical level through improving 3G receive characteristics is itself conservative, so also are the estimates of the benefits realised, based as they are, on licence fee bids only. In monetary terms we can expect the real net present value of the benefits of releasing 5-10 MHz in the 3G band to be considerably greater than the €6.2-12.4 bn indicated. Nevertheless, as the table shows, even at the lower end it would be worthwhile to spend at least an extra €50 per terminal to upgrade the estimated installed base of 124 million 3G terminals. Since the likely manufacturing cost increment is far less than €50 per terminal in this kind of mass market environment for hand-held devices, we conclude that the likely costs for introducing the technical improvements discussed would be more than compensated by the economic benefits, and that therefore the 3G industry would probably find this a worthwhile change to make.

Case Study 2: Digital Cellular Mobile - GSM

A set of techniques has been considered by GSM operators, system vendors and other GSM stakeholders to increase the capacity of the GSM networks. One technology that focuses on the performance of the mobile station is referred to as single-antenna interference cancellation (SAIC). SAIC is a generic name for techniques that use signal processing to cancel or suppress interference without the use of multiple antennas and thus allow an increase in the downlink spectral efficiency of GSM networks by modifying the user terminals.

From the analysis of the 3GPP study it has been concluded that an improvement of 1 db to 3 dB in the required C/I at the handset is achieved. Simulations for four different network scenarios showed that this translates into a capacity increase or bandwidth reduction in a range from 5% to 15%.

In Europe some 220 MHz in total is allocated to GSM in the 900 and 1800 MHz bands (2x110 MHz). By improving terminal performance as described, the achievable capacity increase of 5% to 15% corresponds to a bandwidth between 2x5.5 MHz to 2x16.5 MHz, or the equivalent increase in network capacity for any given density of base stations.

To estimate the value due to the receiver improvements we have again analysed the amounts paid by operators in licence fees during the 3G licensing in the period 2000-2003. We have done this because the market value for mobile spectrum today is better reflected by 3G values than by GSM. Mobile operators in Europe are embarked on a migration to 3G, and anything which frees 2G (GSM) spectrum and makes it available for 3G deployment is of great commercial interest. Therefore the same estimates of value, and associated caveats can be applied in the case of 2G efficiency improvements as in the 3G case 1 above.

Bearing in mind these caveats, the results of the analysis are as follows:

Case Study 2: GSM Networks - Adoption of SAIC to improve terminal performance			
			Notes
Assume applies to whole of EC population - million	494		
Benefit each way FDD MHz	Lower Case	5.5	MHz
	Higher Case	16.5	
Imputed value from average 3G Licence Fee - whole of EU - €m	Lower Case	6,823	Licence Fee Value only - other benefits would add to this figure
	Higher Case	20,469	
Assumed 3G penetration at time of introduction		90%	
Estimated Number of GSM terminals to be modified		445	Million
Breakeven additional cost per terminal € at replacement	Lower Case	15.34	
	Higher Case	46.02	

As in the 3G case this analysis is very conservative. While the estimate of how much spectrum can be freed at the technical level through improving GSM terminal receive characteristics is itself conservative, so also are the estimates of the benefits realised, based as they are on licence fee bids only. In monetary terms we can expect the real net present value of the benefits of releasing 5.5-16.5 MHz in the GSM bands to be considerably greater than the €6.8-20.5 bn indicated. Nevertheless, as the table shows, even at the lower end it would be worth spending at least an extra €15 per GSM terminal to upgrade the estimated installed base of 445 million 3G terminals. It is expected that this would be done as customers upgrade their terminals at the end of their practical life (2-3 year cycles in GSM terminal upgrades). Since the likely manufacturing cost increment per terminal is far less than €15 per terminal in the huge and mature GSM mass market environment for mobiles, we conclude that the costs for introducing the technical improvements discussed are will likely be more than compensated by the economic benefits.

Case Study 3: Digital Fixed Radio Systems – Microwave Point to Point

Digital Fixed Radio Systems (DFRS) are used to transmit data between fixed locations. Typically DFRS are implemented by line of sight microwave links that offer high capacities and high reliability. In total approximately 36 GHz of bandwidth is allocated to fixed links in the frequency range of up to 100 GHz. The improvement in receiver performance has been analysed based on a reduction of the carrier to interference ratio C/I required to achieve a given data-rate and Quality of Service. The examinations have been performed for microwave networks with in total 4900 links in the frequency bands 7 GHz, 13 GHz, 18 GHz and 23 GHz. However the technical analysis showed that an improvement in system performance within a reasonable technical range would not result in a significant release of spectrum.

Case Study 4: Digital TV Broadcasting Networks - DVB-T

DVB-T provides digital television broadcast by terrestrial transmitters. Currently DVB-T is being implemented all over Europe and will replace the analogue television systems by the end of 2015. At the regional radio conference in 2006 in Geneva (RRC-06) frequency plans for a number of different reference planning configurations (RPCs) were agreed[51]. While at the preparatory meeting for RRC-06 in 2004 antenna diversity for receivers had been discussed, this technical feature was not considered in the plans agreed during RRC-06. The objective of the analysis which we have performed was thus to determine what benefits could be achieved if receivers with antenna diversity were made mandatory.

The technical analysis shows, that if receivers with antenna diversity become a requirement, this would provide a spectrum benefit of 78 MHz.

There is a strong presumption that the most economically beneficial use of released UHF TV spectrum would be for mobile use - presumably a new band for 3G or beyond - even for 4G mobile?

On this basis we have again conservatively valued the capacity potentially thus released by reviewing the amounts paid by operators in licence fees during the 3G licensing in the period 2000-2003. It is possible that in the 4G environment a greater capacity and revenue potential will be possible per MHz - again our analysis is conservative in this respect. However, the release of spectrum cannot easily take place until analogue television services have been switched off, presumably in the 2012-2015 time period.

Bearing in mind these conservative aspects, the results of the analysis are as follows:

[51] Annex 3.5 of "Final acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)", ITU, Geneva 2006.

Case Study 4: DVB - Introduction of Antenna Diversity to Improve Performance and Release Spectrum		
		Notes
Assume applies to whole of EC population	494	million
Spectrum released each way MHz	39	(total released is 2 x 39 MHz = 78) MHz
Imputed value from average 3G Licence Fee - whole of EU - €m	48,381	Licence Fee Value only - other benefits would add to this figure
Estimated Number of fixed TV Receivers to be modified	181	million
Estimated Number of mobile TV Receivers to be modified	124	million
Breakeven additional cost per terminal € at replacement	159	

Again the analysis of this case is conservative. The estimates of the value of spectrum are based on licence fee bids only. Because of the lower frequency, which is more suitable for robust mobile communications, we can expect the real net present value of the benefits of releasing 78 MHz (2 x 39MHz) in the UHF-TV band will be considerably greater than the €48 bn indicated. As the table shows, it would be worthwhile to spend up to an extra €159 per digital TV receiver to upgrade the installed base. It is expected that this would be done as customers upgrade their TV receivers, but in view of the substantial benefits, it may make sense to subsidise some upgrades to speed the process. Since the likely manufacturing cost increment per terminal is far less than €159 per TV receiver in the huge and mature TV receiver mass market environment, we conclude that the costs for introducing the technical improvements discussed would be more than compensated by the economic benefits.

Summary

The technical analysis carried out during these case studies has demonstrated that an improvement in receiver performance in several different interference environments is technically possible, especially when considering future technical developments in both hardware and software. These improved technologies will lead to increased system capacity and thus to an improved spectrum usage by interference control at the receiver. The economic analysis showed that the cost for such improvements is outweighed by the benefits of the improved spectrum usage.

During the case studies it has also been found that in environments, like the mobile market, where it is beneficial for both system suppliers and spectrum users to invest in spectrally efficient technology, these investments are made without directly imposing such measures.

Recommendation 6.2: It would not be in the interest of economically efficient spectrum use for the Commission to introduce mandatory technical specifications for receivers.

Recommendation 6.3: For many commercial services, the existing interference environment could be made more harsh without significant economic disadvantages for such services. The Commisison should therefore identify services and uses where a relaxation in interference planning criteria could be made to the benefit of enhanced spectrum utilisation.

It is also worth noting that on 13 March 2003 the FCC adopted a Notice of Inquiry entitled "Interference Immunity Performance Specifications for Radio Receivers" during which the FCC sought information on whether it should incorporate receiver interference immunity performance specifications into spectrum policy decisions on a broad basis [52]. On 4 May 2007 the FCC terminated the process with the comment that the proceeding has become outdated and that receiver interference immunity performance specifications may be addressed in proceedings that are frequency band or service specific. [53]

6.4.4 Sharing Spectrum

Interference might occur whenever spectrum is shared between different users or applications. The interaction between services and users will depend on the technology used and the spatial distribution of the transmitter and receivers in the given sharing situation. Thus interference control has to consider both the technical framework- in which interference happens as well as the spatial and geographic dimension of the sharing scenario.

The spatial dimension originates from the physics of radio waves while the geographic dimension arises from man-made boundaries such as national borders or boundaries of an area in which the usage of a given part of the spectrum has been licensed to a given operator. The usage of spectrum on one side of a border will always impact the spectrum usage on the other side (except for frequencies so high or transmitter powers so low that their effective transmission radius does not extend across the border). Thus any spectrum management measure has to be analysed regarding its impact on adjacent areas. The extent of this influence strongly depends on the type of service and its technical parameters. Signals transmitted with high power on low frequencies will propagate much further into adjacent areas than signals with low power on higher frequencies. Thus it is important to consider the size of licence areas in relation to the parameters of the interfering service, or more precisely, in relation to the fraction of the licence area that is affected by the radio service operated outside this area.

One case to deal with is interference over geographic boundaries, another one is to consider interference caused between services that are operated within the same area, either using the same band (in-band) interference or adjacent bands.

A comparable set of interference categories is also found in the Australian interference management model that uses:

- same band-adjacent area in-band interference (category A);

[52] "*Notice of Inquiry"*, ET Docket No. 03-65 and MM Docket No. 0-39, 18 FCC Rcd 6039 (2003).
[53] FCC Order to ET Docket No. 03-65, May 4, 2007

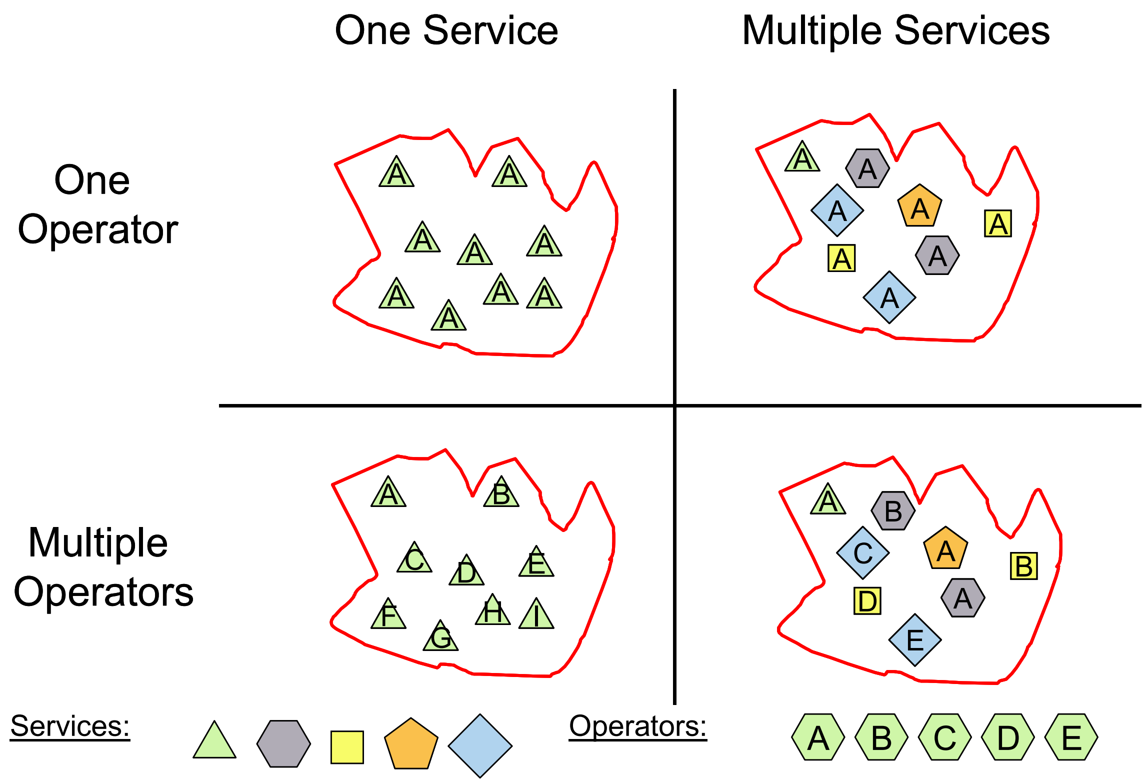
- same area-adjacent band in-band interference (category B); and
- same area-adjacent band out-of-band interference (category C)[54].

However the category “same-band-same area” is not included in this approach. The reason for this might be found in the fact that the Australian licence model does not foresee band sharing by different operators or services within the same area as it is argued that this would make the band unattractive for potential commercial licensees. Thus this approach does not include all possible interference scenarios required to define a coherent definition for harmful interference.

A set of typical sharing-scenarios inside one area are listed below:

- One Service, one operator
- One Service, multiple operators
- Multiple services, one operator
- Multiple services, multiple operators

The following drawings illustrate these scenarios. Different symbols and colours are used to distinguish transmitters for different services; letters inside the service symbols marks operators:



It seems reasonable that the usage of radio spectrum inside a particular area might change over time, operators might wish to change the technology used or additional operators might wish to introduce new services. Thus transition scenarios between operational scenarios that might be typical have been defined below:

[54] “Space-Centric Management” – A General Solution for Equitable Access to Radio Spectrum Spaces under Conditions of Flexible use” Michael Whittaker ITU Workshop on Market Mechanisms for Spectrum Management, January 2007

- Embedding of an additional service operated by a separate operator;
- Embedding of an additional service by several operators;
- Embedding of additional services by the same operator; and
- Embedding of several different services by several operators.

To assess the impact of different geographic and operational sharing a baseline scenario is needed. In the following analyses the benchmark will be the "usage" that can be made by a spectrum user (operator) of a specific amount of spectrum with Bandwidth B in a given area with size $A_{licence}$ where the complete Bandwidth B is available without limitations due to interference from other operators or regulatory restrictions as would be the case on a remote island.

As a measure for the "usability" of the bandwidth within the licensed area, the system efficiency S of the system can be used. Several definitions of S are conceivable, in the following a generic definition is given that considers the achievable spectrum usage within a given bandwidth and a given area:

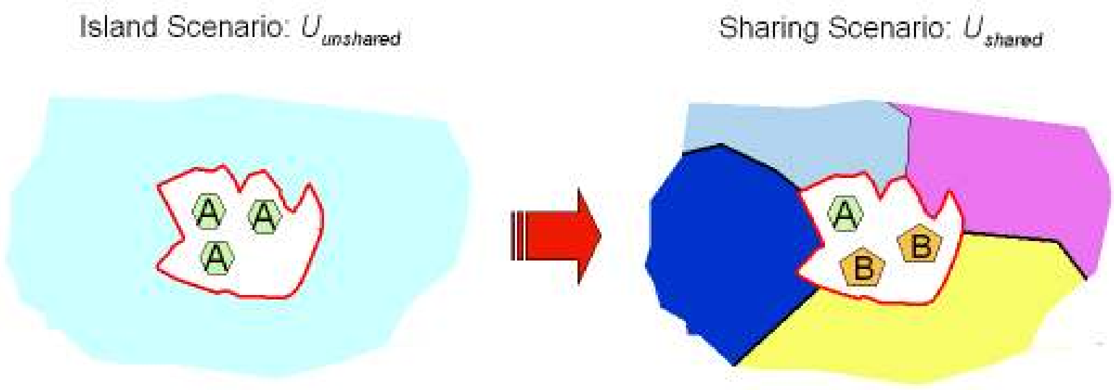
The "*Achievable Usage"* might, for example, be the attainable throughput in MBit/s for a communication system or the number of devices that can be operated in the case of non-communication systems.

It is assumed that this definition for the system efficiency S includes not only parameters of the air interface technology used but also other factors such as targeted quality of service, the network structure, implementation issues, but also impacts of in-band interference arising from radio stations of the operator itself. In the following discussions it is assumed that the spectral system efficiency includes each of these factors and gives an average value for a typical deployment of the technology used.

With such a definition of system efficiency it is found that the maximum use that is achieved within the area in the case of the island scenarios is:

$$U_{unshared} = S \cdot B \cdot A_{licence} \quad (1)$$

The "Island" Scenario will be rarely realised as spectrum will typically be shared over geographic borders and also between different operators in the same geographic area. This will, in general, affect the achievable usability of spectrum inside the area that will change to U_{shared}:



To avoid interference in the case of spectrum sharing, appropriate interference control mechanisms have to be in place. The performance of these mechanisms can be assessed by its sharing efficiency:

$$E_{sharing} = \frac{U_{sharing}}{U_{unshared}} \quad (2)$$

In the following the sharing efficiency in the case of sharing over geographic borders and in the case of different operational sharing scenarios is analyzed further.

Sharing over geographic borders

In the case of spectrum sharing over geographic borders a typical interference management approach is to divide the band in several parts and then to assign the different parts to the operators on both sides of the border such that each operator has exclusive use of the part of the band assigned to it. The advantage of this approach is that each operator can use a part of the bandwidth along the border without suffering from interference originating from interference across the border. Also no information exchange between operators regarding their network deployment is required. The disadvantage of this approach is that an operator will not be able to use the complete bandwidth B over the total area $A_{licence}$. In strip of size A_{share} along the border the operator will only be able to use the fraction c of the total bandwidth. This will reduce the usability of the spectrum, the operator will experience a sharing loss L_{share}. As shown in Annex H the resulting sharing efficiency can be expressed as following:

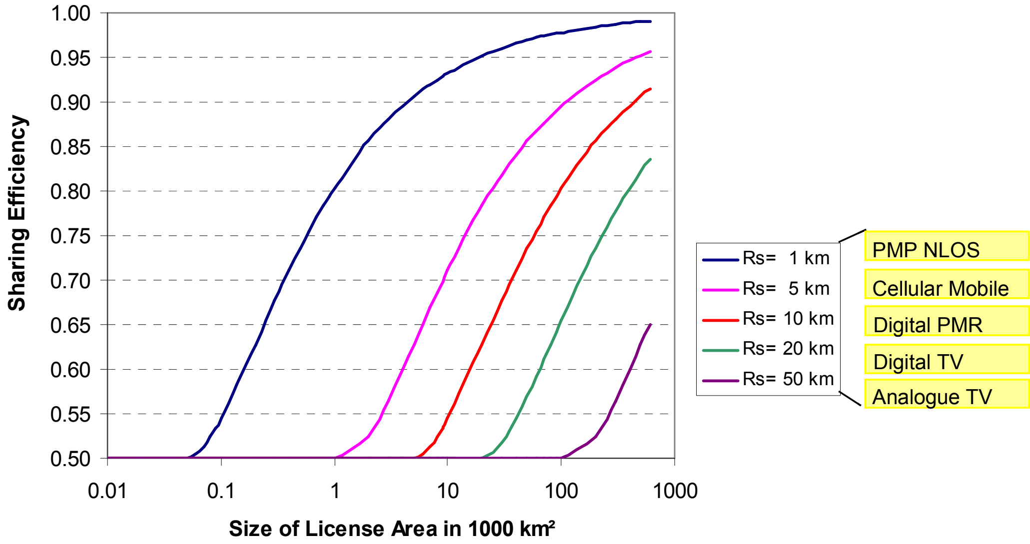
$$E_{sharing} = \frac{U_{sharing}}{U_{unshared}} = \frac{U_{unshared} - L_{sharing}}{U_{unshared}} = 1-(1-c)\cdot\frac{A_{share}}{A_{licence}} \quad (3)$$

The possible range for $E_{sharing}$ can be immediately found from the equation above:

- The maximum found value for the sharing efficiency is one, in case that the complete bandwidth can be used in the total area $A_{licence}$ and thus A_{share} becomes zero. This could be the case if operators A and B were to exchange data regarding their network deployment and coordinate their frequency planning.

- The minimal found value for the sharing efficiency is c in case that the entire licence area $A_{licence}$ is affected by the operator from the other side of the border and no common planning is done.

Clearly the size of the area $A_{licence}$ will depend on the radio service used. An analysis for different services is found in Annex H. The following graph shows one result: the dependence of sharing efficiency on the size of the licence area and the service radius (R_s) for different typical radio services. The analysis has been done for a frequency re-use distance $D = 4.5 \cdot R_s$ and $c = 0.5$:



From this diagram it can be seen that the sharing efficiency depends on the size $A_{Licence}$ of the licence area and the service radios for a single radio station of the transmitter. The larger the size of the licence area and the smaller the service area of a radio station the higher the sharing efficiency. With decreasing size of the licence area the sharing efficiency will reach a lower bound, which is given by the fraction of useable bandwidth c. The conclusion is that band sharing where interference is managed by a band split is only effective for network scenarios where the area in which the service is licensed is very large compared to the area that is covered by a single radio station. In all other cases it is preferable to follow an approach where the spectrum sharing is based on planning that considers both sides of the border, as would be the case in typical coordination procedures in the area of broadcasting.

Spectrum sharing inside the same area

The above sharing scenarios have in common that, in a given area, a part of the spectrum is used in parallel by different services, by different operators or both. From a technical point of view it is not relevant if the same or different operators operate multiple services, as interaction and possible interference between the services solely depends on their technical characteristics and their spatial deployment. Clearly, it seems reasonable that where one spectrum user operates several services a coordination of service deployment will be simpler and, eventually, more efficient than it might be in case between operators. Especially in the case of competing operators it is possible that one operator will hinder, accidentally or intentionally, the spectrum use of another operator. However, this is a question of organizational measures and could be defined in a sharing agreement between operators. From a technical point of view, spectrum sharing between services and operators can be done in one of the following ways:

- Band sharing where the band is divided into sub-bands and each of the services uses a part of the initial band over the complete target area;
- Geographic sharing where each service uses the complete band but in different parts of the service area;
- Temporal sharing where the different services use the same spectrum but not at the same time; and
- Parallel spectrum sharing at the same time in the same geographic region.

Clearly interference management is found in any system that uses multiple access methods like TDMA, FDMA or CDMA to provide several communication channels within a given part of the spectrum. This type of interference management is achieved where interference is avoided by a synchronized system and thus can be considered as a highly coordinated sharing environment. In the following discussion sharing approaches between different systems will be compared against a "Single Operator" – "Single Service" scenario.

In the first instance it seems reasonable that an upper bound for the sharing efficiency is given by $E_{sharing} \leq 1$. However, it is also possible to conceivable of scenarios with $E_{sharing} > 1$. An example would be the case where a transition from "one-operator" / "one service" to "one-operator" / "two services" is implemented where the new technology provides an enhanced spectral efficiency and thus the sharing efficiency becomes:

$$E_{sharing} = \frac{T_{sharing}}{T_{unshared}} = \frac{T_{sharing1} + T_{sharing2}}{T_{unshared}} \quad (4)$$

with

$$T_{sharing1} < T_{unshared}\,; T_{sharing2} < T_{unshared} \text{ and } T_{sharing1} + T_{sharing2} > T_{unshared} \quad (5)$$

For all the above scenarios, except parallel sharing, a transition from a non-sharing to a sharing environment is only reasonable if the bandwidth that has been allocated to a single operator is either not completely used or could be better used if different technologies were implemented. In the first case the operator could consider sharing spectrum, to a certain extent or in some regions, with another operator. In the latter case the operator could adjust spectrum use and system implementation to its needs.

In the “one operator” – “multiple services” scenario it can be assumed that it is in the interest of the operator itself to minimize interference between services. In a “multiple operators” scenario however each operator would likely require a guaranteed maximum level of interference. The definition of such a level of acceptable interference could be part of the sharing agreement either between operators or between operators and the regulatory authority.

A spectrum user that operates in a region that is adjacent to a licence area where a transition from a non-sharing to a sharing scenario takes place will require that its services are not affected by this transition and thus will find a constant operating scenario. One approach to ensure such a constant environment over licence area borders would be a kind of black box approach, where for services in adjacent areas the interference environment is guaranteed while the interference level inside the box can be freely defined between the operators involved or the operators and the responsible regulatory authority. Regulatory means to implement such a black box approach could be to define maximum allowed power densities at the licence area border or to regulate transmit characteristics in a way that the border conditions are maintained.

In a regulatory environment that allows such a flexible spectrum use, sharing could be a benefit for operators, especially in combination with spectrum trading. Yet there are other arguments for and against shared spectrum use, which are beyond the concerns of operators. The following table summarizes possible pros and cons of parties which might be affected:

	Benefit Types	Obstacle Types
To spectrum users / operators	Commercial Flexibility - better business prospects. Technical Flexibility - greater use of assigned band. Cost reduction.	Need more technical capability to mange the band well. Increased interference in-band and cross-band. Technical constraints/impossible. Organizational constraints/impossible.
To spectrum owner (if different from spectrum user)	Commercial Flexibility - better business prospects. Technical Flexibility - greater use of assigned band. Cost reduction.	Need more technical capability to mange the band well. Increased interference in-band and cross-band possible. Technical constraints/impossible. Organizational constraints/impossible.
To consumers	Lower prices due to competition. More choice between services. Service innovation.	Degraded quality of service in case of interference due to sharing.
To regulators	Reduced load on regulator. Simpler system thinkable.	Transition to new approaches.
Social / Public / Economic (beyond direct consumers)	More business for equipment suppliers. Growth in economic activity (e.g. new TV channels mean new content).	Subdivision could result in less usage overall or ineffective usage if not done in a proper way.

A qualitative analysis of possible benefits for the different parties of a transition from a One-Operator / One-Service approach to one of the discussed sharing scenarios is found in the matrix below. It has been assumed that the operated services are only to a certain extent cognitive or frequency agile, thus a certain effort for band management is required. These band management tasks are carried out by the operators.

The following rating scheme has been applied:

(+) The analysed scenario offers a benefit over the defined baseline scenario
(o) The analysed scenario does not offer advantages or disadvantages …...compared to the baseline scenario.
(-) The analysed scenario has some disadvantages compared to the baseline scenario.

Benefit/Obstacle		Base Case: One Service One Operator	One Service Multiple Operators	Multiple Services One Operator	Multiple Services Multiple Operators
To individual spectrum user or operator	Commercial Flexibility and business prospects	**(o)**	**(+)** Multiple Users have commercial flexibility - better business prospects (assume operator has enough spectrum)	**(+)** Commercial flexibility is given as operator can adjust the service and the technology to it's requirements	**(+)** Multiple Users have commercial flexibility - better business prospects (assume operator has enough spectrum)
	Technical Flexibility in network deployment	**(o)**	**(-)** Changes might have to be coordinated between operators	**(+)** Increased flexibility as service and technology can be adapted to business needs	**(-)** Changes might have to be coordinated / cross systems and operators
	Costs	**(o)**	**(-)** additional effort for coordination	**(+)** Can be more cost effective as operator can select service / technology according to business needs	**(-)** Additional effort for coordination **(+)** Can be more cost effective as operator can select service / technology according to business needs
	Technical capability to manage the band	**(o)**	**(-)** Cross operator management might be required	**(-)** Cross service band management might be required	**(-)** Cross operator / cross service management might be required
	Interference in-band and cross-band	**(o)**	**(o)** No increased interference in-band or cross-band if coordination works well	**(-)** Increased in-band interference expected due to different systems	**(-)** Increased in-band interference expected due to different systems
	Technical constraints	**(o)**	**(o)** No technical constraints	**(-)** Constraints due to inter system interference thinkable	**(-)** Constraints due to inter system interference thinkable
	Organizational constraints	**(o)**	**(-)** Additional Resources for management of sharing required	**(-)** Additional Resources for management of sharing required	**(-)** Additional Resources for management of sharing required
To spectrum owner (NRA)	Commercial Flexibility - better business prospects	**(o)**	**(+)** in case on suitable spectrum pricing policy	**(+)** in case on suitable spectrum pricing policy	**(+)** in case on suitable spectrum pricing policy

Benefit/Obstacle		Base Case: One Service One Operator	One Service Multiple Operators	Multiple Services One Operator	Multiple Services Multiple Operators
	Technical Flexibility to use assigned band	**(o)**	**(-)** NRA cannot control use inside the band	**(-)** NRA cannot control use inside the band	**(-)** NRA cannot control use inside the band
	Costs and technical capability to manage the band	**(o)**	**(o)**	**(o)**	**(o)**
	Increased interference in-band and cross-band	**(o)**	**(-)** NRA cannot control interference inside the band	**(-)** NRA cannot control interference inside the band	**(-)** NRA cannot control interference inside the band
	Technical constraints	**(o)**	**(o)**	**(o)**	**(o)**
	Organizational constraints	**(o)**	**(-)** Licence definition might be more complex	**(-)** Licence definition might be more complex	**(-)** Licence definition might be more complex
To consumers	Quality of service	**(o)**	**(+)** Competition **(-)** Bad coordination could reduce quality	**(o)** Neutral unless competition from another band	**(+)** Competition **(-)** Bad coordination could reduce quality
	Prices	**(o)**	**(+)** Competition	**(o)** Unless competition from another band	**(+)** Competition
	Choice of service	**(o)**	**(o)**	**(+)** Different services	**(+)** Competition
	Service innovation	**(o)**	**(+)** Competition	**(+)** Different services allow easy innovation	**(+)** Competition
Social / Public / Economic (beyond direct consumers)	Subdivision could result in less usage overall or ineffective usage	**(o)**	**(-)** Possible losses due to guard-bands etc.	**(-)** Possible losses due to guard-bands etc. **(+)** More use through innovative network design	**(-)** Possible losses due to guard-bands etc. **(+)** More use through innovative network design
	Business for equipment suppliers	**(o)**	**(+)** Due to competition	**(+)** More service platforms needed	**(+)** Due to competition / More service platforms needed
	Growth in economic activity	**(o)**	**(+)** Competition	**(o)**	**(+)** Competition

The matrix shows that in the case of a single operator multi-service model a technology-neutral licensing approach will allow the operator of a band complete freedom to choose the radio technologies deployed and hence the services offered in the band, provided the necessary conditions and constraints are complied with.

Under this approach, where the band operator in a defined geographic area is a commercial company, it will have strong incentives to study the technical and commercial possibilities of different mixes of radio systems and resultant services, and choose a mix which is likely, in its judgement, to achieve the optimum results in terms of investment returns and the associated risks.

If access to the spectrum has been obtained commercially through an auction, the operator has incentives to find the right mix. However, even if the spectrum has been issued subject only to administrative fees, there are still strong incentives from shareholders and normal market pressures to find the optimum mix in terms of investment returns.

Where there are multiple operators and multiple services in a given band and area, the case for benefits needs more careful consideration. On the one hand, the same rationale as for the single operator case applies - there is a positive sum game available to those who use a given band in a given area, but now multiple operators need to coordinate amongst themselves to find the optimum mix of radio systems and services. Finding such a mix will require the facility for spectrum trading between operators. There are more boundaries and interactions between systems and operators to consider, each with their respective spectrum mask and geographic areas. This is a positive-sum game where the resulting benefits can be shared amongst the players/operators. But the larger quantity of boundaries between operators, each with their respective mask and geographic areas, will mean a greater potential for inter-system and inter-operator interference and hence a greater requirement for spectrum monitoring and policing. Under this proposal the first preferred source for coordination efforts is the operators themselves, in whose mutual interest it is to find the optimum mix. But there are many more potential sources of disagreement and conflict within the band and geographic region than in the single operator case. Therefore care will be needed to ensure that the operators compensate the spectrum management agency for the work required.

For a further analysis, the results from the evaluation matrix have been summarized in the table below. For each sharing scenario the number of scored (+) and (-) are listed:

	One Service Multiple Operators			Multiple Services One Operator			Multiple Services Multiple Operators		
	(+)	(o)	(-)	(+)	(o)	(-)	(+)	(o)	(-)
Spectrum User Operator	1	2	4	3	0	4	2	0	6
Spectrum Owner (NRA)	1	2	3	1	2	3	1	2	3
Consumers	3	1	1	2	2	0	4	0	1
Social / Public / Economic	2	0	1	2	1	0	4	0	1

While the table cannot be used for a full mathematical analysis, it does allow certain conclusions to be reached:

- The greatest benefits from spectrum sharing accrue to consumers, mainly due to increased competition and a better choice between different services;
- For spectrum owners, most obstacles identified originate from increased efforts from the management of different technical systems and coordination procedures. However in a licence regime where it is the operators' decision whether to share an allocated band or not, it is a question of a cost/benefit calculation for the operator;
- The main disadvantages for spectrum owners are a loss of control over the band usage and an increased effort for band licensing; and
- In the category "Social / Public / Economic" advantages predominate, but disadvantages could arise through inefficient band usage due to increased interference.

Compared with **Single Operator - Multi-Service**, **Multi-Operator - Multi-Service** will incur higher planning coordination and administrative costs both for the operators themselves and for the NRA in monitoring and policing. If fair and reasonable, administrative charges are paid by the operators to the NRA, then these internal costs and external charges will be taken into account in the search by the operators for the optimum spectrum use mix and there will continue to be incentives for all operators concerned to reach an economic optimum mix of operators and services.

In the **Multi-Operator - Multi-Service model** spectrum management assumes some of the characteristics of the free market, with multiple players, and a minimum of regulatory constraints. The highest achievable incentives for technical and commercial innovation would exist, together with the minimum of regulation, so that levels of innovation achieved would be high, as would of course be management costs. Free markets produce solutions which are an economic optimum: if the market is divided between too many players, then mergers or market exits result in fewer players. If spectrum management is too onerous and costly because there are too many systems in the band then spectrum trading can be used to remove some systems, and so on. In this approach price indicators are freely available to all operators and between the operators and the regulator. This is a feature of a properly operating market, and should result in the market being able to find its own equilibrium and to achieve optimum spectrum use and hence benefits.

Thus it can be expected that the **Multi-Operator - Multi-Service** model will achieve an economic optimum with a high level of technical and service innovation and an acceptable level of spectrum management charges.

Conclusions in a Sharing Area

The analysis of transition scenarios indicated that a transition from a “One-Operator” / “One-Service” scenario to a sharing scenario brings benefits to both consumers and operators. The discussion of technical possibilities showed that band sharing could also lead to improved spectrum utilization.

However, an appropriate spectrum management regime has to be in place to ensure continuity to spectrum users that operate outside the region where such a transition is implemented. The same spectrum regime should also offer enough flexibility to operators that intend to share their bands to adjust the sharing methods and spectrum applications to their needs.

Recommendations

The analysis in the previous section identified general improvements and benefits in spectrum usage due to interference management techniques. It also has been demonstrated that the optimum use of spectrum will be realised when an operator can gain economic benefits from effective spectrum usage. However to avoid misuse, flexibility should only be allowed within pre-defined border conditions.

Recommendation 6.4: The Commission should work towards achieving an interference management regime which:

- enables flexible spectrum use and spectrum sharing between services and operators by using licence terms that do not imply a certain technology;
- works towards low power, small cell services wherever possible in order to allow for better usage of the band edges, both in terms of frequency and area;
- allows spectrum users to gain directly from effective spectrum usage and sharing;
- ensures continuity at licence area borders for users in adjacent areas by defining technology independent border conditions where possible;
- considers technology constraints while determining border conditions and licence area sizes; and
- revisits the definitions on a regular basis in order to consider the current state of technology both in transmitter and receiver technology as well as in accurate compatibility analysis.

Supporting measures which would be essential to achieve such a flexible spectrum management regime would include the clear definition of spectrum rights and provision for ‘spectrum trading’ between spectrum users. Unless spectrum users can realise a financial value from releasing spectrum in whole (trading) or in part (sharing) to others, they will have no incentive to do so.

In order for such spectrum rights to exist, the radio licensing regime should provide that spectrum rights are conferred under licences for considerable periods of time (leasehold arrangements).

Where a band is leased on a nation-wide or regional basis, then subsequent trading becomes easier to contemplate as a band could in whole or in part be traded between parties (the part being traded being defined either by frequency range, geographic extent, or both). Parties to a spectrum trade would need to define the (spectrum or interference) mask they would apply between each other, and would need to continue to conform to existing masks affecting the band edges.

Where spectrum licences provide only for service from defined points (e.g. individual fixed links, PMR base transmitters, etc.) then the spectrum trading market would be far less “liquid”. It would be relatively unlikely that a purchaser would buy such spectrum rights from an incumbent, unless as part of a sale of the underlying business, for example. However, this would not preclude “aggregators” from acquiring all the fixed link licences in a given band and geographic area for example in order to introduce a new application of higher value, even if for example they had to pay the existing users to exit the band.

Provisions as referred to above that if no agreement can be reached, no incursion on “sitting tenants” rights would be allowed should provide safeguards for spectrum users whose motivations might be other than commercial.

7. Inter-Industrial Analogies and Spectrum Implications

Whilst the concept of 'interference' in the form in which we relate to it is, most probably, unique to the radiocommunications industry, there are many other industries where the introduction of something new, or changes in existing systems have potential negative knock-on implications for the status quo. What's more, many such situations are controlled by international or national treaties, laws and regulations. By making analogies between such situations and the introduction of new radio interference sources into an existing spectrum usage ecosystem, it is possible to identify similar situations whereby alternative forms of regulation are used to control 'interference'. These analogies could provide useful insights into the way in which interference could be regulated.

There are many industries with which potential analogies could be made. Here we have outlined a few possibilities. What will be seen is that the overall framework of regulation and control within these diverse industries can be condensed into a small number of concepts which may have direct application to spectrum and interference management.

7.1 Business Re-Engineering – Balancing Risk and Controls against Business Development

7.1.1 Introduction

In the financial services sector, organisations generally approach business initiatives with a focus on improving performance and creating value. These goals drive efforts *inter alia* to automate processes, reengineer a supply chain, acquire or divest assets, conclude joint ventures, or outsource. However it may be that regulatory requirements and control mechanisms prompt a greater focus on compliance and internal controls, efforts that to some may seem separate and dissimilar from efforts to improve business performance and drive value. An increased focus on control and safeguards could be perceived as diverting energy and resources from business improvement without providing compensatory value. However, as organisations increasingly drive business value by balancing risk management and business improvement, regulatory compliance is gaining importance.

Consequentially a focus on compliance and control can be used to facilitate change and integrate a compliance/risk management focus into every aspect of the business.

7.1.2 Developing Good Practice

Once initial compliance with key regulations is achieved, organisations can build on that foundation to improve both their controls and their business processes - ultimately integrating risk management across the organisation and transforming processes. Information on the organisation's controls portfolio provides managers with a different approach for evaluating their businesses. This is not a new phenomenon as these organisations have used other approaches over time - such as ISO 9000, or Total Quality Management. As a business mechanism, controls can become an important means of identifying new opportunities to manage risk, improve business performance, and add value, in both current and future initiatives. A strategic approach is essential to achieve sustained confidence and value.

Historically, many financial organisations have undertaken business initiatives such as new information systems, process reengineering, mergers or acquisitions, or outsourcing with a bias toward business improvement and value. Often controls were addressed late in the process, making them more difficult and costly to implement.

When planning significant business initiatives, organisations have always considered people, process, and technology. Increasingly, the sector is now explicitly considering risk and controls as a key dimension in planning change. Business initiatives need to be executed with a balance between risk and controls across the three dimensions: process optimisation, organisation and people, and technology.

This experience is directly analogous to interference management. Interference is a multifaceted issue involving a multitude of concepts, technical problems, administrative activity and processes. The reduction of interference is a key element in maximising the economic value of spectrum for the benefit of society. Effective controls applied to the three dimensions would help to achieve this goal.

7.1.3 Controls as a New Approach

Controls require a related objective. To appreciate whether the right controls over the right things are in place, finance managers have been urged to address their organisational objectives – financial reporting, operations, and compliance. Then the pertinent questions can be answered: "Do the controls in place help in the achievement of the objectives? Is the information available which we need to determine if the objectives are to be realised? Do the controls enable the effective and efficient use of our limited resources?" These questions also echo the concerns of all spectrum managers.

Understanding the nature of effective controls will help our understanding of how controls can be used to manage risk and identify opportunities for business or to effect improvements in the European interference management regime.

In basic terms, a control is an activity that establishes a need for action or validates information. Controls should be embedded in processes as well as the IT systems that enable them to realise their organisational objectives and manage associated risk.

Controls in the finance sector are established to ensure, for example, that vendors are correctly paid, that inventory is safeguarded and managed, or that a sale was properly recorded. Large, financial institutions have literally thousands of controls, managed by a large number of employees. This underlines the importance of ensuring that the organisation has the right controls, at the right point in the processes. Such sentiments are directly pertinent to the management of interference.

The flow of information in a large financial organisation is multilayered and complex. Financial and performance information typically flows up, down, and across the entity and is used intensively throughout. For example, when a loan is made, the information generated may include such factors as interest rate (variable or fixed), the index to which variables are tied, payment frequency, maturity date, and information regarding the underlying collateral. This then feeds into reporting mechanisms and functions dealing with interest rate risk analysis etc.

Understanding the scope, magnitude, and impact of controls across the organisation requires a specialist approach. Using such an approach, an organisation can assess its controls from different perspectives - such as by business units, applications, geographies, risk concentrations, or management objectives. These perspectives can be addressed in a similar manner across four key control dimensions - automated versus manual and detective versus preventive. This analysis is critical in assessing enterprise needs for controls evolution.

For interference management, key demographics within a controls portfolio could be preventive or reactive approaches to the interference environment, where to concentrate effort and whether processes can be further automated.

Any organisation should have a multifaceted view of the quality and quantity of the controls it employs – an in depth analysis of only one perspective would provide an incomplete understanding of the situation. Such a multi-targeted approach helps an organisation to understand where its greatest challenges and opportunities are likely to occur.

7.1.4 Linking Controls with Business Performance

Efforts to comply with external requirements such as new financial regulations can stimulate a management understanding of the nature of their controls, processes, and systems; where they are located; and by whom they are performed. An analogy here might be an initiative by the Commission, by means of a Decision to consider interference management at the European level as well as at Member State and local levels. How to develop necessary procedures for compliance is information that for many companies (and regulatory authorities) probably does not exist at all or does not exist in a single location. A stimulant such as a regulatory mandate could help to focus management attention on the need to analyse processes and controls, in order to improve the functioning of any organisation. The process also provides an opportunity to create additional business insights by taking a controls portfolio view.

Armed with a vast array of information, organisations are now beginning to understand how their controls are linked to business performance - and what changes may be needed to balance their controls portfolio as the business itself changes. Otherwise, existing controls may become irrelevant and their cost unnecessary and new risks may arise that are not addressed by appropriate controls.

For many companies in the finance sector, regulatory intervention has resulted in an opportunity for organisations to rethink how they do business, gaining an understanding of the relationship between controls and business improvement.

7.1.5 Summary

Regulatory compliance has driven many financial institutions to assemble information about risks, controls, processes, and systems in one place. Having made the investment in initial compliance, management is able to leverage that effort in various ways. A high level as well as detailed analysis of their controls portfolio, for example, can help organisations identify areas in which they can enhance risk management, reduce costs, and improve business processes. Thus they can embed controls (and the information about them) into systems and processes and, ultimately, balance a focus on risk and controls with efforts to improve performance.

7.2 IT System Management

7.2.1 Introduction

For technology managers, keeping pace with software patches and system configuration changes to combat ‘hackers’ has become an increasingly difficult job in the past few years. The challenge is causing a radical change in the way many manage information technology security. Instead of waiting until attacks occur and hoping tools such as firewalls and intrusion-detection systems catch them before they inflict serious damage, many organizations have taken the offensive by hunting vulnerabilities before they are exploited. This is vulnerability management. Organisations that are successful in this regard have deployed the right mix of security tools, policies and procedures. A vulnerability management programme often includes a collection of technologies and procedures that form a management process. Programme components vary according to specific organisation needs. However the core approach usually follows a common path and includes the following steps:

- Compare priorities to current security [interference] policies
- Inventory technical assets [ensure system records are accurate]
- Evaluate the risks
- Develop an action plan
- Evaluate effectiveness

It would seem that interference management could be analogous to vulnerability management and some of the techniques employed could be translated into the spectrum management sphere.

7.2.2 Vulnerability Management

Vulnerability management programmes often include a collection of technologies and procedures that form a management process. Programme components vary according to specific needs. However the core approach usually follows a common path and includes the following steps.

Step 1 - Compare priorities to current security policies

An IT department is likely to be responsible for implementing a vulnerability management programme. Contact should first be made with senior management to identify which systems they think are critical to maintain minimally acceptable operations and what concerns they have about such systems. Subsequently it is necessary to determine what policies and procedures are already in place for handling the systems and data. It is then necessary to ascertain whether IT employees already run vulnerability scans and how do they respond to vulnerabilities and whether existing procedures meet management expectations.

This step would be analogous to examining, analysing and documenting current interference management processes.

Step 2 – Establish an inventory of technical assets

It is necessary to identify every device and system on the network. In order to keep track of constantly changing networks, it is also necessary to full document the network topology. Ownership of assets is also important as well identifying who is responsible for various network elements. It is then required to set priorities in order to determine which assets are most important for the organisation. This will identify where an organisation is at most risk.

From an interference management standpoint this step would equate to ensuring system records are in place as well as identifying the key processes that would be needed to provide an acceptable quality of service.

Step 3 - Evaluate the risks

A commercial or open-source software tool should be used to scan devices and systems for vulnerabilities. Possible problems will include incorrect settings and configurations and un-patched software and operating systems. In addition the network itself needs to be assessed to determine how exposed the network is to outside influences.

Vulnerabilities are then correlated to the asset inventory. The intent is to identify the vulnerabilities that pose the greatest risk to the most important systems. Vulnerability management is a matter of risk assessment as well as the ability to analyse an entire organization.

Step 4 - Develop an action plan

Once vulnerabilities have been discovered and the risks assessed, it is necessary to decide what action to take and when. A decision is required as to whether the most vulnerable systems should be addressed immediately; an issue in this regard might be whether such an action would cause too much disruption. If so other means of mitigating the vulnerability may need examination; alternatively a method to block an attack on the asset would need to be formulated. Such a course of action could require a new rule or policy, physically modifying a system or including a detection device in order that any attack could be seen in real time.

Step 5 - Evaluate effectiveness

The vulnerability assessment process must be evaluated to assess success whether it successfully identified and reduced vulnerabilities and how closely the results comply with the organisation's policies and objectives.

In most cases a review will demonstrate that more work is necessary. It is likely that the vulnerability identification and mitigation steps will need to be repeated. Vulnerability management is often a repetitious process, the goal is to get as close as possible to continuously monitoring vulnerabilities to identify security issues in software as soon as an attack is identified.

7.2.3 Summary

Vulnerability management in the IT industry is pro-active and therefore different from more familiar reactive approaches, such as firewalls and intrusion detection. Vulnerability management involves finding a weakness in something that hasn't been attacked. In the past vulnerability management in the context of IT security meant scanning the network with stand-alone instruments maybe once every six months to determine which systems might be at risk, and then manually loading software patches or resetting mis-configured systems.

The latest trend is to combine many of the elements needed for vulnerability management into a single, centralised solution that automates many of the processes involved. A crucial ingredient for successful vulnerability management is having the support of senior management since responsibility and accountability for security compliance runs through an entire organisation and the process needs to involve all.

It is interesting that the techniques described in Section 6.1 of this report and this section both require resources to be expended on monitoring the system and taking preventative action in the form of controls to avoid problems occurring rather than taking action to solve problems once they have occurred.

7.3 Filing of Flight Plans

Managing air traffic typically involves ensuring that the majority of air traffic is routed along a series of narrow but tightly managed corridors. It is more straightforward to manage and control the traffic within these corridors than if air traffic were allowed to roam freely within the skies. Air traffic controllers ensure that a minimum of physical separation is maintained between any two aircraft and thus, by keeping them apart, the risk of a collision is minimised. Outside the controlled areas, pilots of individual flights use their own equipment to avoid collisions and different flight rules apply.

The air traffic within the corridors is mostly on pre-defined flight plans indicating the majority of the parameters of the journey (height, direction, time and so forth). This provides a significant measure of pre-planning and co-ordination and thus reduces the burden of day-to-day management and operation. These pre-planned routes are modified from time to time and form the baseline usage of the flight corridors. However, there are occasions when additional flights may be required to traverse the routes or where additional or new routes need to be added to the existing plan.

Whilst the detail of air traffic management is not, in itself, necessarily a good analogy for radio spectrum management (though take-off slots at airports are often considered a scarce resource), the concept of an external agency managing a resource which is used for both pre-planned, scheduled use as well as ad-hoc occasional use does bear some analysis.

One could envisage a situation in which spectrum usage is monitored by an independent body (possibly the regulator or administration). Scheduled, pre-planned usage would therefore be checked though loosely controlled. However through a knowledge of actual usage, additional requests could potentially be scheduled or even allowed on an ad-hoc basis. This kind of activity could take place on a short or long-term basis such that both regular and sporadic requirements could be accommodated. In such a situation, the monitoring organisation would take control of ensuring that interference was controlled within allowable limits and users would have some certainty that their use of the spectrum would be controlled and policed.

Such a situation is similar to that which is often proposed for the use of cognitive radio. One of the issues with cognitive radio is that, whilst a piece of spectrum may appear unused from a given location, it may be in use at a nearby location which is shielded from the location of the radio by physical obstacles. The use of a monitoring system located at a position affording a better (unshielded or high) overview, or collecting information from many or all radio users, to keep track of radio usage and then transmit this usage information to interested parties is one solution proposed to allow cognitive radios to overcome the shielding issue. Expanding this concept to all licensed spectrum usage (e.g. that in ‘corridors’) may bring additional benefit. Clearly outside of such controlled areas, usage could be controlled by the users themselves in the same way as flights in uncontrolled airspace.

7.4 Modifications and Additions to Railway Infrastructure

Like many systems which have been built up over several decades, the infrastructure on which railways operates is complex and sensitive. Equipment and services have been designed so as to maximise throughput (passenger traffic) whilst maintaining appropriate levels of safety and cost. In most countries, any change to the infrastructure requires a number of safety case analyses to be conducted to determine:

- The change in risk probability of the loss of human life;
- The technical impact of the change on existing infrastructure;
- The operational impact of the change on existing services.

The cost of the changes is then weighed up against these factors, amongst others. This is not, in a sense, a true cost-benefit analysis as the cost is almost a secondary factor. Typically a separate cost analysis is conducted to determine the likely impact of a change on costs. This is independent of the safety case analyses which must be done and often submitted to a regulatory authority for approval, before the change can be made. In the case of instances whereby the risk of loss of life is significantly reduced (such as major infrastructure overhauls), there may be no cost analysis as such, as the work will bring unquantifiable benefit.

If there is a significant impact on the infrastructure or on the operation of services, it may be possible for the party wishing to instigate the changes to negotiate with the infrastructure or service provider or providers to arrive at a mutually beneficial outcome, or indeed to compensate one or other for the detrimental effect that the change may make. The safety case analyses are relatively widespread. The impact of each new change on almost every element of the overall system must be demonstrated – even if the effect is nil.

The analogy to radio interference is, perhaps, quite close. The economics of introducing a new (or the modification of an existing) radio service into the spectrum are almost independent of the technical analyses required to ensure that the new service will not exceed interference thresholds. A licensee might first conduct a commercial analysis to decide whether or not a new system will be worthwhile, before looking at its impact on other radio services. Again, there may be situations whereby the costs are less relevant, especially where safety-of-life radio systems are in question. There are equally cases whereby the impact of a service may be detrimental to neighbouring radio users and in which there exists an opportunity to negotiate a mutually beneficial outcome or financial compensation.

If we played out this scenario from a spectrum perspective, the role of the regulator would become one of approving such changes from a ‘global good’ perspective. In other words, it would be up to the regulator to ensure that any new systems, or changes to existing systems, were in the greater interest of the society of spectrum users, or at least did not inconvenience or cause unwanted detriment to other users. The licensee wishing to make the change would submit a number of ‘safety cases’ or their equivalent to the regulator who would review these before making a decision as to whether the service should go ahead. Thus the driving factor for changes would come directly from spectrum users rather than being driven by regulatory decisions and action.

Possibly one difference between the railway and radio is that there is no need for a holistic approach when considering the radio perspective. Services and users who are far removed (in frequency) from the changes being proposed are highly unlikely to suffer any consequences.

7.5 Comparisons and Conclusions

There are many analogies which can be drawn between spectrum use and other industrial regulatory regimes. Few, if any, other industrial situations can be, in totality, analogised to spectrum regulation, however there are many aspects of these industrial comparisons which can be used to consider alternative ways in which spectrum might be managed. Below we discuss the general techniques which may merit further consideration.

7.5.1 Risk and Impact Analyses

In many industries, the existing situation (the status quo) has been reached through a series of changes, each of which has only been reached following complex analysis of the impacts that would occur should that change be allowed. Such analyses would have allowed some changes to take place, but would have denied others because the risk of severely (or even slightly) upsetting the status quo is too high.

Typically such decisions are taken through risk analyses, whereby a series of usually pre-defined and pre-agreed tests are conducted, the results of which can be used to assess the likelihood of the impact of any changes being significant. The concept of risk analyses is commonplace in situations where safety of life is at stake, when the risk of loss of human life can be assessed and a simple decision taken as to whether any increased risk is permissible (it is, of course, possible, that the risk could be reduced).

A risk analysis typically measures the effect of a change on one particular criterion (e.g. the loss of life). A wider consideration of the effects of a change can be undertaken through an impact analysis in which the overall impact of a change is considered. For example, whilst a specific change may provide a decreased risk of loss of life, it may also increase pollution or raise costs. Such risk and impact analyses are often used in situations where changes are being made to complex ecosystems.

In a sense, many of the compatibility studies which are undertaken are essentially risk analyses (or in some cases impact analyses). The way in which the results of such analyses are used differs from that which other industries may use the same kind of tests. In the radio spectrum situation, compatibility studies are often not pre-defined in as much as the required outcome (for a go / no-go decision) is defined as part of the input to the study. The result of the study is then a decision as to whether or not to allow the change. In many industries the required outcome or outcomes are pre-defined (e.g. a percentage probability increase in loss of life) and, assuming that the proposed change can be shown to meet the necessary criteria, it is allowed. Whilst in the existing spectrum regime, it could be argued that the outcome would be unique to each analysis, if the outcome were to be defined in terms of increased risk of interference to existing systems, using an interference management technique may open up the spectrum to many new systems if they could be shown to have an appropriate, pre-agreed risk of increasing interference. Thus, the use of interference management instead of more traditional spectrum management approaches may, even from the basis of compatibility study bases, allow greater flexibility of and opportunity for use.

7.5.2 Regulatory Push versus Industry Pull

Regulatory change in many industries is either driven by a push from regulators or is pulled along by the industry itself (with regulators dragging along behind). Spectrum regulation has typically been a combination of both with some changes having been made for regulatory reasons but arguably most having been driven by changes in the radiocommunication industry. One thing which does vary between industries, however, is the speed with which change can take place. Due to the international nature of spectrum management, to institute and agree changes can take nearly 10 years as changes work their way through the agenda of various World Radio Conferences. In some instances, much faster changes have taken place, often at a national or sub-regional level, with the WRC agenda playing catch-up as the changes are eventually agreed and ratified.

There ought to be scope for the international aspects of radio regulation to be more fluid with changes being effected on an as required basis, rather than being on a fixed date. With the advent of better communications, it would be possible to circulate requests for changes to all parties and have a vote at a set date thereafter in order to try and expedite changes. Other techniques could be used to speed decision making, although the concept of more fluid regulation fits better with the increasing demand for spectrum.

Other regulatory mechanisms might be used to effect the same changes. For example, if more spectrum were tradable the market could, to a large extent, dictate possible future uses. At a European level, it may be possible to enable or encourage methods for more rapid change of use of spectrum.

7.5.3 Pre versus Post-Change Control

There are two differing and alternative approaches used when considering when to apply regulation or to take action: before or after a change. In almost all situations, changes of use to radio spectrum follow a reactive regulatory approach, i.e. regulatory mechanisms and controls are put in place before changes are allowed. Whilst it may not seem appropriate to consider post-change regulation due to the way in which radio systems inevitable interact to produce interference, there may, nonetheless, be ways in which post-change controls may be appropriate. This is especially the case where radio systems are introduced in a highly deregulated environment. The situation in the current 2.4 GHz ISM band might provide on example of post-change control wherein the introduction of a new service has a direct impact on all existing services, but where those existing services adapt and modify their own transmission parameters to cope with the interference caused by the new service.

On a longer-term basis, it could be argued that even existing spectrum regulation is, in a sense, post-change control in that many changes take place before international regulations can catch up. However in most cases, the changes will have gone through some local pre-change regulatory check before being actioned.

Further consideration of the use of post-change or post-introduction controls and in particular a consideration of the timescales over which such changes could or should take place and to which types of service they should apply may benefit more flexible spectrum use. If technology can be used to manage usage within certain bands (for example, through the use of cognitive radio principles) there may be greater scope for adjusting regulatory controls and timescales to match.

7.5.4 Controlled versus Uncontrolled Usage

Some of the industrial analogies considered (in particular that of flight paths) offer possibilities for both controlled and uncontrolled use where some areas are under direct control of a regulatory entity (whether hands-off or real-time hands-on) as well as areas where usage has a much lighter regulatory touch. Clearly this dichotomical approach already exists in spectrum management in that there are (an increasing number of) licence exempt, lightly licensed bands (often termed spectrum commons). However there may well be scope for defining additional lightly controlled bands; indeed the move towards traded spectrum reduces controls in these bands.

One could alternatively consider some bands which are controlled directly by the regulator (those requiring a high degree of protection, for example) and others where control is vested in users. These user-controlled bands could be in addition to spectrum commons, with tighter controls but agreed between users, subject to overall limitation set by the regulator.

7.6 Summary

Risk assessment has become a key tool in most industries for looking at matters such as the likelihood of death or injury occurring as a result of a change in working practices; the impact on profits as a result of a change in infrastructure usage; or the operational impact of a change in the provision of existing services. Compatibility analyses are concerned with the likelihood of interference occurring in a changed environment. Evaluating sharing possibilities only on the basis that harmful interference would be unlikely to occur under certain technical conditions ignores the usefulness that overall risk assessments could bring to the process. In such assessments the cost benefits of regulatory action or socio-economic considerations could be fully explored as well as the fundamental technical assessment.

As these approaches fundamentally address the tests carried out to determine the outcome of any change, there is a clear relationship with compatibility analyses. As such, in our consideration of compatibility analyses in section 4 of this report, we have taken an approach which considers the various mechanisms explored and identified in this section.

ANNEXES

A. Glossary of Abbreviations

AFA	Adaptive Frequency Agility
AGA	Air Ground Air
AID	Animal Implant Devices
AMI	Active Medical Implant systems
APC	Automatic Power Control
ARNS	Aeronautical Radio Navigation Service
ATPC	Automatic Transmitter Power Control
BC	Broadcasting
BS	Base Station
BSS	Broadcasting Satellite Service
BWA	Broadband Wireless Access
CDMA	Code Division Multiple Access
CENELEC	European Committee for Electrotechnical Standardisation
CEPT	European Conference of Postal and Telecommunications administrations
DAT	Digital Aeronautical Telemetry
DECT	Digital European Cordless Telecommunications
DFS	Dynamic Frequency Selection
DMO	Direct Mode Operation
DSSS	Direct Scrambling Spread Spectrum
DTH	Direct To Home
DVB-T	Digital Video Broadcasting - Terrestrial
ECA	European Common Allocation table of frequency allocations and utilisations
ECC	Electronic Communications Committee (of CEPT)
ECO	European Communications Office (of CEPT)
EEA	European Economic Area
EECMA	European Electronic Communications Market Authority
ETO	European Telecommunications Office (of CEPT)
EESS ES	Earth Exploration Satellite Service – Earth to Space
EIRP	Effective Isotropic Radiated Power
EMC	Electro Magnetic Compatibility
ENG-OB	Electronic News Gathering – Outside Broadcasting
EPIRB	Emergency Position Indicating Radio Beacon
ERMES	European Radio MEssage System
ESV	Earth Stations onboard Vessels
ETSI	European Telecommunications Standards Institute
EU	European Union
FAT	Frequency Allocation Table
FCC	Federal Communications Committee
FFH	Fast Frequency Hopping
FM	Frequency Modulation
FS	Fixed Service

FSS SE	Fixed Satellite Service – Space to Earth
FWA	Fixed Wireless Access
GSM	Global System for Mobile
GSM-R	GSM for Railways
HCM	Harmonized Calculation Method
HEO	High earth Orbit
HF	High Frequency
HI	Harmful Interference
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
ITS	Intelligent Transport System
ITU	International Telecommunication Union
JRC	Joint Research Centre of the European Commission
LBT	Listen Before Transmit
LDC	Limited Duty Cycle
LF	Low Frequency
MarMob	Maritime Mobile
MetAids	Meteorological Aids
MIMO	Multiple Input Multiple Output
Mob	Mobile
MVDDS	Multichannel Video and Data Distribution Service
N	No
NATO	North Atlantic Treaty Organization
NIB	Non Interference Basis
NRA	National Regulatory Authority
NRF	New Regulatory Framework
PAMR	Public Access Mobile Radio
PFD	Power Flux Density
PMR	Professional (Private) Mobile Radio
PTMP	Point to Multipoint
PTP	Point to Point
R&TTE	Radio and Telecommunications Terminal Equipment
RA	Radio Amateurs
RAS	Radio Astronomy Service
RFID	Radio Frequency Identification
RNS	Radio Navigation Service
RNSS	Radio Navigation Satellite Service
RR	Radio Regulations (of ITU)
RSC	Radio Spectrum Committee (of EU)
RSPG	Radio Spectrum Policy Group
RTTT	Road Transport & Traffic Telematics
RX	Receiver
SAB	Services Ancillary to Broadcasting
SAP	Services Ancillary to Programming

SEAMCAT	Spectrum Engineering Advanced Monte-Carlo Analysis Tool
SFH	Slow Frequency Hopping
SOLAS	Safety of Life at Sea
SR	Short Range
SRD	Short Range Device
TAPS	TETRA Advanced Packet Services
TDMA	Time Division Multiple Access
TEDS	TETRA Enhanced Data Services
TETRA	TErrestrial Trunked Radio
TETRAPOL	Trunking standard from EADS Telecom (Formerly MATRA)
TRRL	Tactical Radio Relay
TV	Television
TX	Transmitter
UHF	Ultra High Frequency (usually defined as frequencies between 300 and 3000 MHz)
UIC-DMO	International Railway Union (system) Direct Mode Operation
ULP	Ultra Low Power
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wide Band
WAPECS	Wireless Access Policy for Electronic Communications Services
WiFi	Acronym for Wireless LAN systems based on the IEEE 802.11 series of specifications
WiMAX	Worldwide Interoperability for Microwave Access
WLL	Wireless Local Loop
WRC	World Radiocommunication Conference (of ITU)
WTO	World Trade Organization
Y	Yes
YM	Yes but marginal
YR	Yes with Restrictions

B. Analysis of CEPT Reports dealing with ECC Compatibility Studies

Incoming Service	Band	Sharing with	Result	Reference Doc.	Notes
PTMP – Mob - BWA	3400 – 3860 MHz	PTP FS SAB/SAP Mob FSS SE RL	YR YR YR Y	ECC Report 100 Compatibility studies in the band 3400-3800 MHz between Broadband Wireless Access (BWA) systems and other services	 Aeronautical SAB an issue Spurious emissions from < 3.4 GHz
ITS - Mob	5855 – 5925 MHz	RA FSS RL SRD FWA RTTT FS	Y Y YR YR YR YR Y	ECC Report 101 Compatibility studies in the band 5855 - 5925 MHz between Intelligent Transport Systems (ITS) and other systems	ISM 5725 – 5875 MHz. 5875-5905 MHz ITS not likely to cause/suffer interference.
TEDS - Mob	380 – 470 MHz	PMR PAMR AGA	YR YR YM	ECC Report 99 TETRA Enhanced Data Services (TEDS): Impact on existing PMR/PAMR and Air Ground Air (AGA) systems in the 400 MHz band	In adjacent channels Extensive co-ordination required
Euroloop – FS (leaky – feeder)	9.5 – 17.5 MHz	RA MIL BC	YR YR YR	ECC Report 98 Studying the compatibility issues of the UIC EUROLOOP system with other systems in the frequency band 9.5 to 17.5 MHz	
CDMA and TDMA MSS	1610-1626.5 MHz	CDMA TDMA	N N	ECC Report 95 Sharing between MSS systems using TDMA and MSS systems using CDMA in the band 1610-1626.5 MHz	Frequency separation required between CDMA/TDMA MSS systems
UWB - Mob	3400 – 4800 MHz	WiMAX - FS	YR YR	ECC Report 94 Technical requirements for UWB LDC	LDC mitigation required

				devices to ensure the protection of FWA systems	
Medical Implants - Mob	401 – 406 MHz	MetAids EESS - ES MetSat EPIRBs >406	Y Y Y Y	ECC Report 92 Coexistence between Ultra Low Power Active Medical Implants devices (ULP-AMI) and existing radiocommunication systems and services in the frequency bands 401-402 MHz and 405-406 MHz	
ESV – mob sat	5925 – 6425 MHz	FS	YR	ECC Report 91 Compatibility of Earth Stations on board Vessels transmitting within the gaps in the CEPT Fixed Service channel plan for the lower 6 GHz band (5 925-6 425 MHz) (incl Excel calculation sheet)	Possible to utilise gaps in FS plan with defined ESV parameters
Wind Profiler Radars - RL	1270 – 1295 MHz	RNSS	YR	ECC Report 90 Compatibility of wind profiler radars in the Radiolocation Service (RLS) with the Radionavigation Satellite Service (RNSS) in the band 1270-1295 MHz	Mitigation techniques generally required
UMTS	880-960 MHz 1710-1880 MHz	GSM UMTS	YR Y	ECC Report 82 Compatibility study for UMTS operating within the GSM 900 and GSM 1800 frequency bands	
ULP-AID	12.5 – 20 MHz	All Services	Y	ECC Report 81 The coexistence between Ultra Low Power - Animal Implant Devices (ULP-AID) operating in the frequency band 12.5-20 MHz and existing radiocommunication systems	
FWA	5725-5875 MHz	RL RTTT FS PTP FSS ES	YR YM YM YR	Compatibility studies in the band 5725-5875 MHz between Fixed Wireless Access (FWA) systems and other systems	DFS required to avoid HI FWA vulnerable co-channel to be avoided Co-ordination required Orbit requires protection

		SRD RA	Y YM		Some interference to FWA possible FWA Vulnerable co-channel to be avoided
Inductive SRDs	<30MHz	All services	YR	ECC Report 67 Compatibility study for generic limits for the emission levels of inductive SRDs below 30MHz	New limit proposed with additional national measures
UWB	<10.6 GHz	All services	YM	ECC Report 64 The protection requirements of radiocommunications systems below 10.6 GHz from generic UWB applications.	20-30dB more protection than FCC mask required. But see ECCC/DEC/(06)04
TETRA-TAPS MOB	870-876/915-921 MHz	Tactical Radio Relay MOB	YM	ECC Report 58 Compatibility between TETRA release 2 taps and tactical radio relays in the 870-876 and 915-921 MHz bands	Frequency and geographical separation required.
SRRadar	79 GHz	RL RAS RA	- YM YR	ECC Report 56 Compatibility of automotive collision warning Short Range Radar operating at 79 GHz with radiocommunication services	Not in use Radars would need to deactivated near RX HI possible but statistically unlikely
FS (increase of power)	Circa 58 GHz	FS	YR	ECC Report 54 Analysis of increasing the EIRP of Terrestrial Fixed Links at around 58 GHz	Increasing EIRP but not TX power advocated
BSS - HEO	620-790 MHz	RAS	YR	ECC Report 47 Protection of the Radio Astronomy Service from unwanted emissions of HEO BSS systems operating in the band 620-790 MHz	PF limits advocated
SRR	23-26 GHz	FS	YM	ECC Report 46 Immunity of 24 GHz automotive SRRs operating on a non interference and non-protected basis from emissions of the primary Fixed Service operating in the 23	

				GHz and 26 GHz frequency bands	
UMTS/IMT-2000	2500-2690 MHz	MSS MMDS	N YR	ECC Report 45 Sharing and adjacent band compatibility between UMTS/IMT-2000 in the band 2500-2690 MHz and other services	Not possible in same geographical area Geographic separation required
CDMA-PAMR	917-921 MHz	GSM < 915	YR	ECC Report 41 Adjacent band compatibility between GSM and CDMA-PAMR at 915 MHz	2.15 MHz separation not sufficient - co-ordination and filters required
CDMA-PAMR	872 – 876 MHz	SRDs < 870	Y	ECC Report 40 Adjacent band compatibility between CDMA-PAMR mobile services and Short Range Devices below 870 MHz	Minimal problems
CDMA-PAMR	410-470 MHz	Analogue PMR	YR	ECC Report 39 Technical impact of introducing CDMA-PAMR on 12.5 / 25 kHz PMR/PAMR technologies in the 410-430 and 450-470 MHz bands	Separation/Filters required for adjacent frequency usage
CDMA-PMR	870-921 MHz	GSM-R UIC-DMO	YR	ECC Report 38 The Technical Impact of introducing CDMA-PAMR in the 870-876 / 915-921 MHz band on 12.5 kHz UIC DMO & 200 kHz GSM-R radio systems	Separation/Filters required for adjacent frequency usage
PMR/PAMR	Circa 900 MHz	TRRL	YR	ECC Report 34 Compatibility between Narrowband digital PMR/PAMR and tactical radio relay in the 900 MHz band	Frequency/Geographic separation required
FWA	3.4-3.8 GHz	FWA	YR	ECC Report 33 The analysis of the coexistence of Point-to-Multipoint FWS cells in the 3.4 - 3.8 GHz band	Deals with introduction of new FWA systems in presence of existing systems. Antenna discrimination key issue
AMSS	14-14.5 GHz	FS FSS	YR YR	ECC Report 26 The compatibility & sharing of the aeronautical mobile satellite service with	

		MSS	YR	existing services in the band 14.0-14.5 GHz	
TAPS	380-470 MHz	PMR (analogue) PAMR	YR	ECC Report 22 The technical impact of indroducing TAPS on 12.5 / 25 kHz PMR/PAMR technologies in the 380-400, 410-430 and 450-470 MHz bands	Guard bands necessary and geographical separation at frequencies around the duplex transition frequency for TAPS BS TX to PMR BS RX
FSS, EESS, FS, SRD and video SAP/SAB	10.6 – 10.7 GHz	RAS	YR	ECC Report 18 Compatibility and sharing studies between the RAS operating in the band 10.6-10.7 GHz and other services	Frequency separation and filtering required at RAS station to reduce impact of adjacent band usage
SAP/SAB	10.6 – 10.68 GHz	EESS	YM	ECC Report 17 Sharing between EESS (Passive) and video SAP/SAB links in the band 10.6-10.68 GHz	Mobile cameras not feasible – temporary links may be possible.
TAPS	Circa 900 MHz	UIC-DMO	YR	ECC Report 14 Adjacent band compatibility of UIC Direct mode with TETRA Advanced Packet Data Service (TAPS)	Minimal problems
TAPS	870 MHz	SRD	YR	ECC Report 13 Adjacent band compatibility between Short Range Devices and TETRA TAPS mobile services at 870 MHz	Frequency separation required
ULP-AMI	9-315 kHz	RA BC MarMob FS RNS	Y Y Y Y Y	ECC Report 12 Ultra Low Power Active Medical Implant systems (ULP-AMI)	
LF-RFID	135-148.5 kHz	Broadcast	Y	ECC Report 07 Compatibility between inductive LF RFID systems and radio communications systems in the frequency range 135 - 148.5 kHz	

DAT ENG-OB	2700-2900 MHz	ARNS	YM	ECC Report 06 Technical impact on existing primary services in the band 2700 - 2900 MHz due to the proposed introduction of new systems	Safety Service considerations
TETRA	Circa 915 MHz	GSM BS	YR	ECC Report 05 Adjacent band compatibility between GSM and TETRA Mobile Services at 915 MHz	Physical separation and/or filtering required
LF/HF - RFID	135-148.5 kHz 4.78-8.78 MHz 11.56-15.56 MHz	Radio navigation	Y	ECC Report 01 Compatibility between inductive LF and HF RFID transponder and other radio communications systems in the frequency ranges 135-148.5 kHz, 4.78-8.78 MHz and 11.56-15.56 MHz	

C. INTERFERENCE INFORMATION SHEET

1 Introduction

……………………………………..is responsible for regulating the use of radio in this jurisdiction. We are also responsible for collecting interference statistics, which are important for planning the future use of radio frequencies in an efficient manner.

Harmful Interference means interference which endangers the functioning, degrades, obstructs, or interrupts a radiocommunication service to an extent beyond that which would be expected when operating in accordance with applicable Community or national regulations.

Interference is caused when unwanted signals, which can come from a range of sources, are picked up by your radio, television or other equipment in a way which leads to your reception quality being adversely affected. Interference may prevent reception altogether, may cause only a temporary loss of the desired signal, or may affect the quality of the information, sound or picture produced by your equipment.

Interference to consumer electronics equipment is a frustrating problem; fortunately there are several ways to deal with it. This document provides information for reducing or eliminating the interference.

If the interference problem is not solved or sufficiently reduced by following the steps in this document, you should follow the instructions in the owner's manual of your equipment for contacting the manufacturer. If the manufacturer of your equipment is not listed, the Internet is an excellent source of information for finding contact details.

If after attempting to resolve your interference problems by the methods outlined in this information sheet you are still experiencing harmful interference, please complete the form at the end of this document and we will contact you as soon as possible.

2 Check the Installation of Your Equipment

Many interference problems are the direct result of poor equipment installation. Equipment which is not CE marked may have insufficient shielding or inadequate filtering and may also cause your equipment to react to a nearby radio transmitter. This is not the fault of the transmitter and little can be done to the transmitter to correct the problem. If a correction cannot be made at the transmitter, actions must be taken to stop equipment from reacting to the transmitter. These methods may be as easy as adjusting your equipment or replacing a broken wire. These and other simple corrections may be accomplished without the help of a service technician.

2.1 Simplify the problem

Begin by disconnecting all equipment from the piece of equipment you are trying to fix. For example, if you are working with a television set, disconnect your DVD, VCR, set top box, stereo speaker wires and video game. Then, reconnect each of these additional devices individually to determine which device may be causing the interference to your television. Do the same thing for a telephone or stereo system. Disconnect all answering machines, telephones, CD players, facsimile machines, modems, etc. If the problem goes away when a device is not connected you have found the problem. It may be necessary to filter the device which reacts adversely to the transmitter.

2.2 Check your connections

Make sure all cables are properly formed, connected and in good condition. Antenna wires, interconnecting cables and power leads often act as antennas and carry the interference into your system. All wires and cables should be as short as possible. If there are any loose connections or broken and damaged cables replace or repair them with good quality cable and connectors. If you are using the services of a cable television operator, contact your cable company for assistance.

You should also test all splitters used in your system, if there are any. A splitter is a device that provides a signal to more than one location. To test the splitter, bypass it by connecting the antenna or cable connector directly to one TV. If the signal quality is improved or the interference goes away, the splitter is defective and should be replaced.

2.3 Check your amplifier

If you are using an amplifier between the antenna and your equipment, temporarily disconnect the amplifier and bypass it. By doing this, you allow the signal from the antenna to go directly to the TV or radio receiver. If the interference disappears, then the amplifier is causing the problem.

If your TV or radio receiver is connected to a master antenna television system (MATV), commonly used in large apartment complexes, you should contact the building management for assistance.

2.4 Check your antenna system.

Even though your antenna does not have moving parts, the wire and the antenna can physically deteriorate due to the effects of time and harsh weather. Replace damaged or broken antennas. If the antenna is badly corroded clean or replace it. Check the incoming wire from your antenna for physical damage. If you are currently using an inside antenna, try to replace it with an outside antenna to improve the signal.

If after following the steps described above your system continues to react to the interference, you should continue reading this information sheet.

3 Identifying Other Sources

3.1 Simplify the Problem

As a general rule, the more complex a system is, the more difficult it is to isolate a problem. Always start with the simplest system possible; one telephone, one television receiver, or just the Hi-Fi equipment.

For example, if your television is reacting to a nearby radio transmitter, remove all accessories, such as video games, VCRs, stereo system connections and amplifiers.

If the interference improves when you disconnect any device, you are on the right track. You must now make a decision. You can attempt remedial action, contact the manufacturer for assistance, or replace the device with one that does not react to the nearby transmitter. If you choose remedial action continue with this section.

3.2 Collect Information about the Interference

Since 1 January 1996 new televisions and radios have been required to have minimum standards of protection against interference and carry the CE mark to indicate compliance. This has been helpful; however, even with good quality equipment, interference can be a problem. Some basic information about the interference will help a lot in identifying its source.

When do you get the interference?

Keep track of the time of day you usually receive the interference. Do you get interference only at dinnertime? Does the interference occur day after day at the same time? Does the interference occur at all times or is it unpredictable?

If your equipment is reacting to the transmissions of a nearby radio operator, you will have the interference only when the radio operator is talking. The pattern will be much like that of a normal conversation (although it may seem garbled or distorted) except that you will hear only one half of the conversation. Usually the interference will occur for brief periods during specific times of the day.

If the interference is constantly present, it is not caused by a nearby radio operator. You may have electrical, broadcast, or another form of interference.

What does the interference sound like?

Listen carefully to the interference. Read this section and see which part best describes the interference you are experiencing.

On a conventional analogue AM or FM radio do you hear music and voices from a broadcast station in the background? If so, try to identify which station you hear.

Do you hear radio operator voices? Are the voices garbled? If the interference is intermittent and you hear clear or garbled voices, you are probably picking up the transmissions of a nearby CB or amateur radio operator. If so, you will probably be able to see an antenna mounted on their house or car.

Do you hear static, or a constant buzzing sound like food frying? If so you may be picking up interference from an electrical device in either your house or your neighbour's house. You could also be picking up interference from electrical power lines. If the buzzing noise only occurs for short periods of time, you may be receiving interference from a household appliance, such as a motorised lawn mower, hair dryer, vacuum cleaner, or electric drill.

If you are experiencing intermittent interruptions to a digital DAB or DRM radio ensure that you have checked the items in 2.1, 2.2 and 2.4 above. If you are still receiving unexplained outages or drop-outs, check whether neighbours are experiencing the same problem. If they are there may be an interference source in the area. If not, check whether your radio works satisfactorily at a nearby location. If it does you may have a source of interference in your house or premises.

What does the interference look like?

a. Electrical Interference

On an analogue television receiver electrical interference will often be seen as two or three horizontal lines on the television screen and may be accompanied by a loud buzzing or sizzling sound through the TV speakers or stereo system. Often the lines move upwards on the television screen and may be present for hours at a time or for a few seconds at a time. In severe cases, the entire screen may be covered with rolling horizontal lines.

A simple means to discover if the source of interference is in your home or premises is to deactivate electrical circuits by switching circuit breakers sequentially in the main fuse box. Using your TV set to determine whether the interference is active, identify the circuit in your house that is powering the device causing the interference. Be very careful to avoid contact within anything in the box except the circuit breakers. Switch off one circuit breaker at a time. If the interference stays on, turn the circuit breaker back on and try the next. When you turn off the power to the circuit that supplies power to your TV to test that circuit, plug the TV into another circuit.

If the interference stops when a circuit breaker is turned off, go to the area that receives the electricity supplied by the disconnected circuit. Turn the power back on and wait until the interference is present. Next unplug each device on the circuit one at a time. If the interference stops after you unplug a device, you have found the culprit. The device causing the interference must be repaired or replaced. Remember that the device might be hidden or unexpected. For example, you may have a bad amplifier in your attic, or a defective doorbell transformer that is connected directly to the power circuit, a defective charger for your mobile telephone or even a problem in your security alarm panel.

An alternative method for locating electrical interference is to tune to a quiet frequency on your AM (long or medium wave LF/MF) radio during daylight. If you hear static or a buzzing sound, check to see if it corresponds with the interference to your TV or telephone. If it does, use the portable radio as a detection device to locate the source of the interference.

The noise will be loudest in the room where the interference is originating. Unplug each electrical device in the room one by one until the interference stops.

If you cannot locate the interference source in your own house, check with your neighbours to see if they also receive interference. The house that has the worst interference will most likely be the source of the interference. If your neighbour has strong interference, you may wish to try to track it down with a portable AM radio or run the circuit breaker test described above.

If you determine that the interference is not caused by any device in your home or that of your neighbours, contact the customer service department of your local electricity supply company.

b. Analogue Television Interference

Picture 1: Normal TV Reception

The following pages illustrate what many common types of interference look like on a TV set. Find the one that best matches your interference. Use Picture 1 for comparison with the other pictures in this section.

TV stations are intended to serve viewers only within the coverage areas from their transmitters. You can improve picture quality by raising the height of your antenna or using a more directional antenna. Check your antenna cable and connections. Check the antenna is pointing in the direction of the transmitter. Compare with the direction of neighbours' antennas.

Picture 2: Poor TV Signal

Picture 3: Ghosting

Double images of a TV signal, or "ghosting", is a common problem with off-air TV reception in urban areas. Ghosting may be caused by the TV signal being reflected off of a tall building or mountains. Ghosting may also indicate problems with the TV antenna or antenna cable. You may need to install a directional, outdoor antenna.

Images from two different programmes may appear on your TV screen when your set simultaneously receives two TV signals. Co-channel interference looks much like ghosting, except that the two images maybe different, as though one picture has been placed on top of the other. If the problem is caused by weather conditions (temperature inversions), it is usually of a temporary nature. Installing a more directional, outdoor antenna, or relocating your indoor antenna may also improve reception during such conditions. You may also experience similar interference if you are receiving signals leaking from a cable TV system. If you believe that you are receiving cable TV stations but are not a cable customer, inform the cable TV company.

Picture 5: Ham/CB Transmitter Interference

This picture may appear on your TV screen when your set is reacting to an electrical device operating in or near your home or premises. Home appliances and electrical equipment, such as hair dryers, electric razors and electric drills may cause temporary problems, especially if they were purchased prior to 1987 when the EMC Directive was introduced. You may choose to live with this type of interference or purchase a more recent appliance. You may also experience intermittent problems from other home appliances, such as refrigerators and air-conditioners. For example, you may notice interference on your TV when your central heating system cycles on or off. If the interference is continuous, it may be caused by power line equipment. For information about possible remedies, see Section 4.

Picture 4: Co-channel Interference

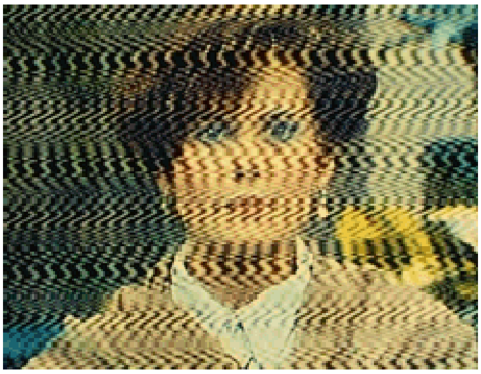
This picture may appear on your TV screen when your set is reacting to signals from a CB, amateur, police, or another radio transmitter. The pattern will appear only when the operator transmits. The "lines" in the interference pattern may be wider, or may seem to "roll" through the TV picture. If your TV is reacting to CB or amateur radio transmissions, you will often hear the operator's voice, although it may be garbled. If you are very close to the transmitting antenna, the TV screen may "black out" when the operator transmits. It is also very common to pick up the CB or amateur operator's voice on the telephone or on your radio or stereo system. For information about possible remedies see Section 4.

Picture 6: Electrical Interference -- very noisy (hair dryer)

Picture 7: Electrical Interference -- low noise

Doorbell transformers are a common source of interference to TV reception. This interference looks like snow or bars on the TV screen. It looks very much like electrical interference, except it does not cover the whole screen. It appears as bars of electrical interference. A frying or sizzling sound comes and goes at about seven second intervals (the intervals may vary). The interference may also be received at significant distances from the source. If you suspect that you are experiencing interference from your own or your neighbour's doorbell transformer, and are unable to locate the transformer, you may wish to contact a qualified technician.

This pattern may appear on your TV screen if you are picking up signals from an FM broadcast transmitter. For information about possible remedies, see Section 4



Picture 8: FM Broadcast Interference

Picture 9: Computer Interference

This type of picture may appear on your TV screen if you operate a computer in close proximity to the TV antenna. The interference may look like electrical interference or a series of diagonal dashed white lines among other patterns. Computer interference will usually occur only when the computer is very close to the TV antenna. You may try to relocate your antenna or computer cables, or move the computer or TV set to another location. For information about possible remedies, see Section 4.

Low power radio devices, such as garage door openers also can cause interference. This pattern may appear on your screen, if you are picking up signals from a garage door opener or radio frequency doorbell.

Picture 10: Garage Door Opener

Amplifiers are sometimes used to help receive weak or distant TV signals. Amplifiers may be installed at the TV set, at the TV antenna, or even in the attic. Although booster amplifiers do increase the TV station signal strength, they may also cause interference to your TV or even your neighbour's TV. They may also amplify interfering signals. A variety of patterns may appear on your TV screen because of amplifier interference. Sometimes a wavy pattern may appear, or the screen may black out for a short time. If your antenna system uses an amplifier, you should disconnect it and turn it off. Next connect your antenna directly to the TV. If the interference disappears, your amplifier should be repaired or replaced. If you continue to experience interference after disconnecting your amplifier, you may be receiving interference from a neighbour's amplifier. If several of your neighbours are experiencing interference, the one with the most severe interference is probably the one with the defective amplifier. Amplifiers may also generate interference when used near strong signal sources, such as TV and radio broadcast stations, business radio stations or amateur radio stations.

c. Digital Television Interference

If you are experiencing intermittent interruptions to a Digital TV, firstly ensure that you have checked the items in 2.1, 2.2 and 2.4 above. These issues are particularly important in respect of digital television and more information is provided below.

Nearly all digital receivers provide an on-screen method of checking signal quality and signal strength. Digital TV signal quality is the most important of these parameters as very low signal quality reading will mean that your receiver will be much more prone to domestic or outside interference leading to picture freezing, pixelation, break up and dropouts.

Digital television can be particularly prone to electrical interference which can also lead to the digital TV picture freezing, with momentary pixelation or total break up. Electrical interference problems are always likely to be worse on a loft antenna.

If your home or premises is surrounded by tall trees or where multi-path reception is experienced, it is not uncommon for signal quality to go up and down as the trees or antenna moves in high winds. Wet leaves will attenuate signals even more especially in the UHF TV bands. It will help if you:

- Re-locate your digital TV compatible antenna or raise its height.
- Try an external roof top high gain TV antenna. Loft antennas are more prone to bad weather signal loss.

- Securely anchor your Digital TV antenna to prevent any movement in high winds.

Antenna Down-lead Troubleshooting
Where Digital TV interference, pixelation or picture breakup is experienced, always check the quality and condition of the coaxial cable used as a down-lead from your antenna. Any cable joins should be visually checked. To get the best DTT reception, double screened coaxial cable should be used. Old TV antennas can let in water if mounted externally, so always check antenna coaxial cables for signs of water ingression or copper corrosion if your Digital TV picture is breaking up.

Joining Coaxial Cables
Badly joined coaxial cables can result in serious Digital TV signal loss. The only acceptable method of joining TV coaxial cables is by using two male F type plugs and a female to female F Type adaptor. If the coaxial cable join is to be left outside, waterproof it by stretching self amalgamating tape around the whole assembly.

Faulty TV Plugs and Faceplate Sockets
Check the wiring of all coaxial plugs from the antenna to your Digital TV receiver to ensure that they are properly fitted on all peripherals and at the TV itself. Also check the wiring in all rooms for poor installation. The screen of the coaxial cable must be corrected connected to the shield (earth) of the TV faceplate socket and the cable terminated in a tidy fashion.

Digital TV Interconnect Cables
The coaxial cables used for interconnecting all TV peripherals must be double screened, to avoid interference pickup and radiation. If poor quality coaxial cable is used to interconnect set top boxes, noise and interference will be picked up by the cables, possibly giving rise to interference and consequential serious degrading of picture quality.

Many coaxial cables provided with Digital TV set top boxes are of poor quality, having inadequate screening, leading to interference pickup problems. These single screened coaxial cables are unsuitable for DVB-T Digital TV installations. The use of poor quality coaxial cable to interconnect video recorders, and Digital TV receivers is the most common cause of TV interference and poor picture quality.

If you are still receiving unexplained outages or drop-outs, check whether neighbours are experiencing the same problem. If they are, there may be an interference source in the area. If not, check whether your Digital TV works satisfactorily at a nearby location. If it does you may have a source of interference in your house or premises.

d. Summary of Possible Interference Sources

1) Broadcast

- AM Radio Station
- FM Radio Station
- TV Station

2) Two-way Radio Transmitters

- Citizens Band (CB)
- Amateur
- Taxi
- Police and other emergency services

- Business
- Airport/Aircraft
- GSM and other public telecommunications services

3) Electronic Communications Networks including Cable TV, Telecommunications networks and LANs

4) Electrical Devices

- Doorbell transformers
- Toaster Ovens
- Electric Blankets
- Fans
- Refrigerators
- Light dimmers
- Touch controlled lamps
- Fluorescent lights
- Aquarium or waterbed heaters
- Computers and video games
- Microprocessor Controlled Equipment
- Switch mode power supplies
- Battery chargers
- Neon signs
- Alarm systems
- Electric fences
- Loose fuses
- Sewing machines
- Hair dryers
- Electric toys
- Calculators
- Cash registers
- Lightning arrestors
- Electric drills, saws, grinders, and other power tools
- Air conditioners
- TV/radio amplifiers
- TV sets
- Automobile and motor lawn mower ignition noise
- Sun lamps
- Smoke detectors

4 Remedies

WARNING - TO AVOID ELECTRICAL SHOCK, ELECTRICAL OR ELECTRONIC EQUIPMENT SHOULD BE WORKED UPON ONLY BY QUALIFIED SERVICE TECHNICIANS

Before you attempt any of the following solutions, you should ascertain if moving the affected device eliminates the interference. This will often prove to be a simple and effective solution. For example, you may notice that your living room TV has perfect reception, while the bedroom TV experiences unacceptable interference. Generally the greater the distance between the affected device and the interference source, the less severe the reaction will be.

If you believe that you are receiving interference through connecting cables or the antenna lead, you may wish to wrap several turns of the cable through a snap- together ferrite core.

It is always best if the affected device is modified in your home while it is reacting to the interference. This will enable the service technician to determine where the interfering signal is entering the equipment.

4.1 OFF-AIR or CABLE TV RECEPTION PROBLEMS

If you have reception problems such as a weak TV signal, ghosting, or co-channel interference, see Section 3.2 b of this information sheet.

4.2 TWO-WAY RADIO INTERFERENCE

The steps listed below may help you to eliminate TV interference that you experience from CB, amateur or other two-way radio stations. High-pass filters, common-mode chokes (choke filters), snap-together ferrite cores and ac-line filters are available from electronics suppliers and in the case of amateur radio stations the operator may be able to obtain suitable filters for you. If your TV or VCR has insufficient filtering or shielding, you may not be able to correct the interference yourself. You will have to obtain help from the manufacturer.

Check to see if the TV volume control affects the interference level. If it does, in the case of interference from HF (short wave) amateur or CB operators install a "high-pass filter" next to the antenna input socket on the TV. This is a filter which will not allow signals in the lower part of the radio spectrum to pass through it. The name "high pass filter" is all you need to know to purchase one. If the local transmitter is operating on a frequency near to the TV frequency, you may need to install a "notch" or "band-reject" filter at the TV’s antenna input socket. The filter must be designed to reject the specific transmissions that you are receiving. The filter supplier should be able to assist you with your selection, however if you are purchasing filters from abroad you should take steps to find out the operating frequency band of the local transmitter. Your national telecommunications regulatory authority or spectrum management organisation should be able to help in this regard.

If you still receive the interference after installing a notch filter and/or high pass filter install a common-mode filter and/or common-mode choke at the TV input.

If the TV volume control has no effect on the interference level or you are still experiencing the interference disconnect the antenna lead from the TV set. If you still have the interference with the antenna disconnected, install an AC mains filter at the electrical power socket your TV is plugged into.

Also try wrapping three or four turns of the TV set's power lead through a ferrite core. Do this as close to the TV set as possible. You may also install a ferrite core in the antenna cable where it enters the TV set. You local electronics store should know what a ferrite core is and should help you select an appropriate one.

4.3 FM BROADCAST INTERFERENCE

Interference from FM broadcast transmitters may arise if you live close-by. Installation of an FM broadcast band rejection filter at your TV antenna input socket, as well as use of a highly directional antenna may reduce your problem. You may also wish to reposition the location of your equipment to attempt to minimise or eliminate the problem(s).

Problems may also occur if you are using an amplifier. Amplifiers are devices used to increase signals from distant stations and frequently react to strong nearby signals. If you suspect this is the case, you should install an FM band rejection filter or a tuneable rejection trap in the antenna line between your antenna and amplifier. Some amplifiers have built in filters you simply switch on or off. Consult the instruction manual for your product. In extreme cases it may be necessary to install a second filter. Repair or replace the amplifier if it is defective.

4.4 INTERFERENCE TO VIDEO CASSETTE RECORDERS (VCRs)

A VCR is really a television receiver without a screen. The solutions for interference from local transmitters and broadcasting described for television interference above, also apply to VCR interference. If these do not work, contact the VCR manufacturer for alternative solutions.

4.5 COMPUTER INTERFERENCE

Interference from computers may disrupt TV reception and reception of other signals in your and neighbouring premises. Check all computer connecting cables. Also try wrapping three or four turns of the connecting cable through a ferrite core. Greater distances between the TV and computer may also solve the problem.

4.6 TELEPHONE EQUIPMENT INTERFERENCE

Telephone interference generally happens because telephones are not designed to operate near radio transmitters and the telephone improperly operates as a radio receiver.

Contact the telephone operator if you are using a rented phone. The telephone operator may be responsible for alleviating interference to the phones they supply.

Disconnect all of your telephones and accessories such as answering machines and take them to one telephone socket. Connect each instrument, one at a time, and listen for the interference. If you hear the interference through only one telephone, the interference is being generated in that unit.

Install a filter on the telephone line cord at the end nearest the telephone and/or at the telephone handset cord.

Filters are very selective. They must be designed for the type of interference you are experiencing or they will not work. For example, if your phone is reacting to an Amateur or a CB radio transmitter, install a filter designed for that purpose. FM broadcast interference requires a filter designed to reject FM broadcast stations. AM broadcast interference requires a filter designed to reject AM broadcast stations, etc.

Filter the incoming telephone line with snap-together ferrite cores. You may need to experiment to find the best style of core and the best location on the telephone lead.

If you cannot eliminate the interference using the above techniques, you should consider purchasing an interference free telephone which has been specifically designed to be immune to interference.

Cordless telephones use radio frequencies and are normally exempt from licensing; consequentially they are unlikely to receive regulatory protection from interference. If you are receiving nearby transmissions on a cordless phone your only recourse is to contact the manufacturer for assistance.

4.7 ELECTRICAL INTERFERENCE

If you have determined that electrical interference is coming from within your home or one of your neighbour's homes, you should disconnect the defective equipment and replace it or have it repaired.

Devices such as electric razors, hair dryers, electric drills and saws can also cause temporary interference problems. Interference from such devices is however decreasing in EU countries due to the introduction of the EMC Directive in 1987. You may choose to tolerate this type of interference since it is temporary and often expensive to eliminate. You may also wish to contact the manufacturer for assistance.

If you determine that the interference is not caused by any device in your home, or a neighbour's home, contact the service department of your local electricity supply company. Most electricity supply companies will investigate the problem and take steps to correct it.

4.8 INTERFERENCE TO OTHER EQUIPMENT

Hi-Fi equipment, electronic organs, computer speakers and intruder alarms etc, can react to nearby radio transmitters. When this happens, the device improperly functions as a radio receiver. You should first determine what type of interference you are receiving and choose a filter designed for your needs. Also you may contact the manufacturer of your product or the installer in the case of alarms to fit a filter appropriate to your needs.

D. RADIO FREQUENCY INTERFERENCE – What you should know

Background

The communication needs of Europe have seen a rapid increase in the last twenty years and as a result, the number of licensed radio stations has risen significantly. Because of this growth, the density of radio signal sources has increased notably, especially in urban areas. During the same period, the electrical/electronic devices available in the market have also seen an explosive growth in their adoption and use by Europeans. Normally, these devices function effectively in a variety of applications; however the characteristics of these devices which have made them economically and conveniently attractive to the public at large, have also contributed to their being susceptible to the effects of local transmitters and other sources of interference. As a result, when such devices are exposed to electromagnetic signals in the vicinity of radio transmitters, they may suffer interference and malfunction. Interference is any unwanted radio frequency signal that prevents you from watching television, listening to your radio or Hi-Fi, or talking on your cordless telephone. Interference may prevent reception altogether, may cause only a temporary loss of a signal, or may affect the quality of the sound or picture produced by your equipment.

Common Causes

Before you can resolve an interference problem you must isolate the actual interference source. Interference originates from many sources - the equipment itself, your residence, or the neighbourhood. The two most common causes of interference are transmitters and electrical equipment. Communication systems that transmit signals (transmitters) are capable of generating interference. These systems include amateur radio transmitters, CBs, and radio and television stations. Electrical interference may be caused by power lines or electrical equipment in your home or premises.

Transmitter Interference

Transmitter interference is normally caused by the actual design of the (interfered-with) equipment itself. Many manufacturers do not protect internal wiring with adequate shielding or sufficient filtering, so the interfered`-with equipment is susceptible to receiving unwanted signals - interference.

Electrical Interference

Electrical interference manifests itself on television and radio receivers. Patterning or pixelation occurs on TV screens. The entire screen may be covered with rolling horizontal lines, bars, or a series of diagonal, dashed white lines or the picture can collapse completely. Short bursts of interference may be caused by hair dryers, sewing machines, electric drills, doorbell transformers and motor mowers. If the pattern is present continuously or the picture collapses completely for long periods of time, it may be caused by equipment that is in use full time, such as aquarium heaters, low voltage lighting or an always-on computer or microprocessor.

Next Steps

If you require further information please request our **Interference Information Sheet**, which provides information on how to solve basic interference problems yourself. The telecommunications regulator in your jurisdiction may also be able to help and will be interested to receive information concerning interference scenarios, which cannot be easily resolved. For further information contact…………………………………..

E. Indicative Amendments to Principal Legal Instruments

E.1 For the Authorisation Directive

Annex A.15 requires amendment to reflect the new EMC directive 2004/108/EC and to ensure the defined term “electromagnetic disturbance” is used to make the cross-reference explicit. For greater emphasis, the formulation “electromagnetic disturbance including harmful interference” might add emphasis to the need for fixed installations such as PLT to avoid harmful interference. It would perhaps also be appropriate to mention the fixed installation provisions in particular.

Annex A.17 which concerns harmful interference via the reference to Article 7(2) of Directive 1999/5/EC (the R&TTE directive) does not require amendment.

For consistency, Annex B.3 should also use the fuller form “electromagnetic disturbance including harmful interference”.

E.2 For the Radio Spectrum Decision

Recitals:
Whereas:

(NEW) Harmonisation may include harmonisation of one or more of frequencies, application and technology. The degree of harmonisation should be the minimum necessary to achieve policy objectives whilst maintaining flexibility, availability and efficient use of the radio spectrum.

(12 – AMENDED) With a view to the adoption of technical implementing measures addressing the harmonisation of radio frequency allocation and of information availability, the Committee should cooperate with radio spectrum experts from national authorities responsible for radio spectrum management. Building on the experience of mandating procedures gained in specific sectors, for example as a result of the application of Decision No 710/97/EC of the European Parliament and of the Council of 24 March 1997 on a coordinated authorisation approach in the field of satellite personal-communication services in the Community (1) and Decision No 128/1999/EC of the European Parliament and of the Council of 14 December 1998 on the coordinated introduction of a third generation mobile and wireless communications system (UMTS) in the Community (2), technical implementing measures should be adopted as a result of mandates to recognised European bodies within whose remit the mandated work falls. Where it is necessary to adopt harmonised measures for the implementation of Community policies which do not fall within such remit, the Commission could adopt implementation measures with the assistance of the Radio Spectrum Committee. Technical implementing measures under Decision No. 676/2002/EC are applicable Community legislation for optimising the use of the radio spectrum and for avoiding harmful interference.

Article 4.2
Amend to: "For the development of technical implementing measures referred to in paragraph 1, the Commission shall issue mandates to one or more recognised European bodies within whose remit the mandated work falls. The mandates shall set out the tasks to be performed, the timetable and other matters relevant to the technical implementing measures concerned. The Commission shall act in accordance with the procedure referred to in Article 3(2)."

E.3 For the R&TTE Directive

Recitals:
Whereas:

Directive 2004/108/EC relating to electromagnetic compatibility defines electromagnetic disturbance for the purpose of specifying protection requirements. Harmful interference is a particular form of electromagnetic disturbance for which special measures relating to putting-into-service of equipment may be appropriate in order to adequately protect the effective use of the radio spectrum and assist the Member States in their responsibilities relating thereto.

Technical implementing measures under Decision No. 676/2002/EC are applicable Community legislation for optimising the use of the radio spectrum and for avoiding harmful interference.

Article 2(i)
Amend to reflect the definition recommended in this report viz: "Harmful Interference means interference which degrades or interrupts radiocommunication to an extent beyond that which would reasonably be expected when operating in accordance with the applicable Community or national regulations."

Article 3.1(b)
Amend to reference the "essential requirements" rather than the "protection requirements" of the EMC directive so that fixed (TTE) installations are dealt with adequately. [Note these recommendations do not address amendments necessary to update references to Directive 2004/108/EC in place of 89/336/EEC.]

Article 3.2
Remove the reference to harmful interference. This recognises that harmful interference is a sub-set of electromagnetic disturbance covered by Article 3.1(b) and liberates Article 3.2 to deal exclusively with effective use of the spectrum by the radio waves emitted for communication purposes. It is also consistent with the provisions of Article 7.2 which provides for effective & appropriate use of the radio spectrum and harmful interference as separate criteria.

Article 7.4
Use the defined term "harmful interference" rather than the undefined one "harmful radio interference" to make it clear that all apparatus, terminal equipment as well as radio equipment, can be subjected to the same procedures for disconnection or withdrawal from service in the event of harmful interference.

E.4 For Commission Decisions (technical implementing measures) under the RSD

2007/131/EC (Ultra Wideband technology - UWB)
2006/804/EC (UHF Radio Frequency Identification Devices - RFID)
2006/771/EC (Short Range Devices - SRD)
In each Decision, replace the definition of “non-interference and non-protected basis” in Article 2 with: “Non-protected basis means that no claim may be made for protection from interference received from radio equipment operating in the frequency bands subject to this Decision and in accordance with other applicable Community or national legislation.”

As a consequence, replace all occurrences of “non-interference and non-protected basis” with “non-protected basis” [Article 3 &, in the case of UWB Recital 14]

2007/98/EC (2 GHz Mobile Satellite Services - MSS)
Add definition to Article 2: “Non-protected basis means that no claim may be made for protection from interference received from radio equipment operating in the frequency bands subject to this Decision and in accordance with other applicable Community or national legislation.”

Delete from Article 3: “Any other use of these bands shall not cause harmful interference to systems providing mobile satellite services and may not claim protection from harmful interference caused by systems providing mobile satellite services.” Replace with: “Any other use of these bands shall not cause harmful interference to systems providing mobile satellite services and shall be on a non-protected basis.”

2005/50/EC (24 GHz automotive short-range radar)
Replace in Article 2.4 “‘on non-interference and non-protected basis’ means that no harmful interference may be caused to other users of the band and that no claim may be made for protection from harmful interference received from other systems or services operating in that band” with “‘non-protected basis’ means that no claim may be made for protection from interference received from radio equipment operating in the frequency bands subject to this Decision and in accordance with other applicable Community or national legislation.”

As a consequence, in Article 3, replace “non-interference and non-protected basis” with “non-protected basis”.

2004/545/EC (79 GHz automotive short-range radar)
Replace in Article 2(c) “‘non-interference and non-protected basis’ shall mean that no harmful interference may be caused to other users of the band and that no claim may be made for protection from harmful interference received from other systems or services operators operating in that band” with “‘non-protected basis’ means that no claim may be made for protection from interference received from radio equipment operating in the frequency bands subject to this Decision and in accordance with other applicable Community or national legislation.”.

As a consequence, in Recital 4 & Article 3, replace “non-interference and non-protected basis” with “non-protected basis”.

F. Technical Aspects on interference Control by Licensing

F.1 Calculation of Interference

Clearly the central pin for interference assessment is found in the receiving radio station with its requirement for satisfactory reception of the signal transmitted by the wanted radio station. In un-interfered environments the thermal noise floor mainly limits reception so minimum requirements are defined in relation to thermal noise

During the design of analogue communication systems, the minimum required *S/N* ratio is used which is computed from the signal strength of the received signal *S* and the power of the thermal noise *N* falling within the receive bandwidth.

For digital communication systems the basic quality measure is the fraction E_b/N_o of received energy per Bit E_b to the thermal noise density N_o that is required to allow signal decoding with a particular bit error rate (BER). The required E_b/N_o depends on the receiver characteristics like modulation scheme and implemented coding methods. For simplicity very often also a minimum required signal to noise ratio *S/N* or carrier to noise ratio *C/N* is given for digital systems that has been derived from the underlying E_b/N_o requirements.

To determine the link quality in interfered environments the interfering power falling into the bandwidth of the receiver has to be determined. For this the spectral distributions of the wanted and the interfering signal have to be taken into account. One way to do this is to calculate the spectral separation following ITU-R SM.337-4[55]. A simpler method can be applied in case that the spectral densities of the wanted and the interfering signal are similar. Under this assumption the calculation can be reduced to a comparison of the power levels. A further simplification is the assumption of a homogenous distribution of the interfering power over the bandwidth of the receiver. In this case the interference can be modelled as an increase of the background noise.

A typical way to technically describe interference is the Carrier to Interference Ratio C/I or the Carrier to Interference plus Noise ratio C/(C+I) which are compared with reference values to determine if a satisfying reception of the wanted signal is possible. Such reference values are for example given in system documentations like TETRA or GSM standards. For these systems required carrier-to-interference ratios for interference originating from a co-channel C/I_C or adjacent channels C/I_A are defined[56 57].

Another way to assess the impact of interference is the calculation of the T/I ratio of the minimum required power level T (receiver threshold) to the interference level I or the degradation of T due to interference. The advantage of this method is that the wanted signal has to be considered during the calculation, thus making this method a worst case analysis.

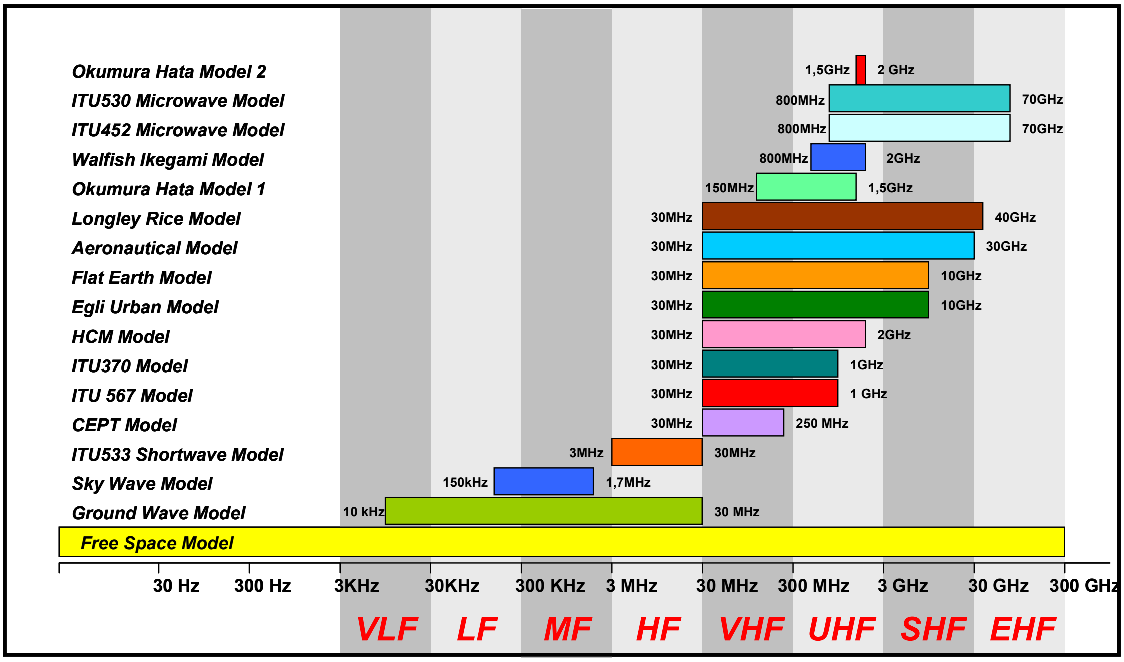
55 " Frequency and Distance Separations" Rec. ITU-R SM.337-4

56 "Terrestrial Trunked Radio (TETRA) Voice plus Data (V+D); Part 2: Air Interface (AI)" ETSI EN 300 392-2

57 "Digital cellular telecommunications system (Phase 2+); Radio Transmission and Reception (3GPP TS 05.05 version 8.20.0 Release 1999) "ETSI TS 100 910 V8.20.0

To perform interference calculations the levels of the different signal at the input of the victim receiver are required. To determine these values the transmit power and antenna characteristics at the involved radio stations and the propagation channel between the radio stations have to be considered. A set of different propagation models is commonly used to determine the attenuation along the propagation path of the signals. Depending on the frequency range, the service type and the type of signal (wanted or interfering) different parameter sets may be used. An example are fixed services where different models are used to determine the wanted signal following the propagation model for interference signals and ITU-R P.530[58] for computation of the wanted signal ITU-R P. 452[59] for the computation of the interfering signal.

The following chart gives an overview on different typical propagation models used during coordination calculations[60]:



These models are not necessarily the best possible analysis of the situation. With more complex models one could often achieve a more precise result. But the methods have been defined based on the understanding that every regulator and operator needs to be able to carry out the analysis by himself. Therefore more complex analysis methods have been banned for a long time. Only during the last decade and based on the fact that computing power is now available for very little money the complexity and thus the accuracy of the methods have increased substantially.

58 "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems" Rec. ITU-R P.530-11

59 "Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz*" Rec. ITU-R P.452-12

60 "SPECTRAemc, User Manual 4.2.0 LS telcom AG, 08-2006

To avoid discussions about them, the calculation basics are often distributed among the parties. So there are cheap or free-of-charge distributions of calculation procedures like the HCM module for mobile or for Appendix 7 or Appendix 8 analysis for satellite coordination. As better analysis in most cases means that the terrain has also to be considered, the terrain data to be used is often shared between the parties. Therefore the members of the Vienna/Berlin/Vilnius agreement are sharing a set of standard topographical data between each other. For other parameters the ITU supplies such items as standard maps for the border line, the rain rate or ground conductivity.

The main advantage is that the agreed methods and input parameters are defined on an international or multilateral basis and therefore will be used by the involved parties (operator, regulator and neighbour countries) in the same manner.

Very often interference does not originate from a single source but comes from several independent interferers. In this case the aggregate interference power has to be determined. The procedures most often used in interference calculations are the following:

- **Maximum procedure.** This is the simplest method for interference calculation. Only the maximum interferer is used. The result is not very accurate but the calculation is very fast and in many cases it is sufficient to obtain a rough overview of an interfering situation.

- **Power sum method.** The power sum method is also a very simple calculation. The square value of all interfering field strength (≈ to the power) is added and the resulting power sum is converted back to the total interfering field strength. As in the maximum procedure, the statistical nature of the field strength is not taken into consideration.

- **Simplified multiplication procedure.**The simplified multiplication method is a standard analysis which is used widely in ITU recommendations. In this method every interfering signal is compared directly with the wanted field strength and a probability value is determined for every single interference value. The total probability is obtained by multiplying all single probability values. This total probability is then used to determine the usable field strength.

- **Lognormal procedure.** The lognormal procedure assumes that all interfering signals follow a lognormal distribution, and that the total interfering signal also has lognormal distribution.

F.2 Technical aspects on interference control by licensing

Methods to Define Technical Parameters in Licences

Independent of the type of licence (site, block, class, soft or licence exempt) the need arises to define technical parameters that have to be met by the systems operated under the licence. Two common methods for defining parameter sets are described below:

- Definition of technical parameters by restricting the usage to a particular technology.

In this approach the various technical parameters for the system are defined in the standard that specifies the technology. The advantage of this method is that technically efficient use of spectrum for a large number of users can be achieved where the equipment standard has been specified to maximise capacity in such situations.

However, a disadvantage of specifying a particular technology is a loss in flexibility of spectrum usage, as not all desirable types of use might be supported by the selected technology. Thus the regulator is required to find out the optimum technology, which can have many adverse consequences.

Examples for licences where the technology to be employed has been defined by a standard include GSM licences.

- Definition of licences that specify a particular type of use (e.g. mobile or fixed) without naming a specific technology.

  In this approach, technical parameters and limitations will be set directly within the licences and not by reference to a specific technology standard. Thus each technology that can operate within the framework defined by the licence is authorised for usage. Thus a higher flexibility is left to the operator to select an appropriate technology in accordance with his needs. Examples of this method to define technical parameters for a licence include the licences for wireless broadband access that currently have been awarded in Germany.

- Definition of licences without naming a specific technology nor a particular type of use

  Besides the aforementioned methods that have been widely used over decades, approaches have also been discussed in recent years where spectrum usage is granted without stipulating a specific technology or a particular type of use. In this case interference control is for example achieved by restrictions to the allowed power flux density (PFD) for in-band and out-of-band interference on the border of the licence area.

Assessment of Interference

During licensing of new radio stations checks and calculations have to be performed to determine if, and to what extent, existing radio stations and services will be interfered with by the new system. The following general approach is used to avoid interference when a new system is being put into operation:

1. Identification of all possible victim systems that might be affected by the new system

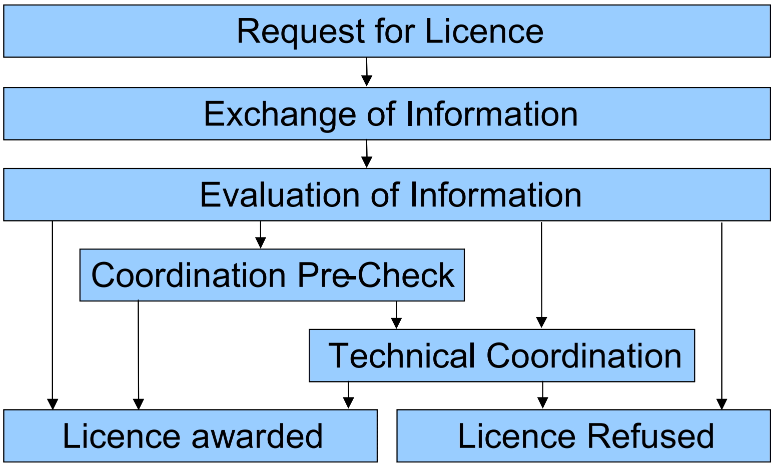
2. Determination for each victim system of the requirements which will allow un-interfered operation.

3. Interference analysis for each affected system to determine if un-interfered operation is still possible with the new system in operation

4. If the conditions for un-interfered operation are fulfilled for all systems identified, the new system can be put into operation. The parameters used during interference analysis are fixed and documented.

Detailed interference calculations will determine whether a new system will interfere with existing systems but they also require sufficient information for all systems involved. The effort to perform the calculations can be rather onerous.

Thus to reduce work load for the identification of victim systems and interference calculations a pre-check is often performed prior to detailed interference or coordination calculations. These pre-checks use simplified procedures to sort out as many systems as possible before detailed calculations have to be performed. The resulting workflow for licensing is depicted in the following diagram:



Interference assessment and calculations are done during "Coordination Pre-Check" and during "Technical coordination" of the shown workflow.

Simplified Coordination Methods / Coordination Pre-Check

The idea behind simplified coordination methods is to sort out as many radio stations as possible before more complicated interference calculations are done. Examples for this approach are the calculations used for land mobile services following the HCM Agreement or the dT/T method applied to satellite links. In both cases not the real interference situation is computed but simplified evaluation criteria are used to determine if more detailed analyses are required or not.

The HCM[61] calculations use field-strength criteria on the border line to determine if further coordination is necessary or not. In case that the received field strength from a radio stations does not exceeded a specific threshold on the borderline it is assumed that the radio station will not cause any interference and thus no further interference calculations will be performed. One advantage of this method is that only the technical parameters of the base station under test have to be known, while no knowledge regarding possible victim stations is required.

The dT/T[62] method for satellite systems uses an increase in the equivalent satellite link noise temperature to determine possible victims of a new satellite link. Only links where the increase due to the new system exceeds a trigger level of 6% are subject to more detailed interference calculations.

[61] "Agreement between the Administrations of Austria, Belgium, the Czech Republic, Germany, France, Hungary, the Netherlands, Croatia, Italy, Liechtenstein, Lithuania, Luxembourg, Poland, Romania, the Slovak Republic, Slovenia and Switzerland on the co-ordination of frequencies between 29.7 MHz and 39.5 GHz for the fixed service and the land mobile service." (HCM Agreement) Vilnius, 12 October 2005

[62] "Method of calculation for determining if coordination is required between geostationary-satellite networks sharing the same frequency bands" Appendix 8 to Radio Regulations.

In both approaches, failure of the pass criteria does not necessarily mean that the new system will cause interference as the parameters and methods used for pre-checking have been selected for a worst-case scenario. Some worst-case assumptions used during dT/T calculations are for example:[63]

- Highest values of wanted and interfering antenna gains;
- Maximum possible power densities of interfering emissions;
- Spectrum shape of the interference gives only the upper bound value of I/N;
- The extent of the frequency overlap between the wanted and the interfered signal is not respected;
- The level of the wanted signal is not taken into consideration; and
- Filtering effects of the receiver are not respected.

The assumptions are taken to facilitate the calculations and to minimize the amount of data that has to be exchanged between the different parties involved in the licensing process. Radio stations that do not pass the coordination pre-check are then subject to further analysis during technical coordination.

Technical Coordination

During technical coordination each new radio station is checked for compatibility with existing radio stations and networks. To allow this, more detailed technical information is required for the new and existing systems. Thus each existing radio station has to be registered with its relevant parameters (technical data as well as licence data like the coverage area and the definition of harmful interference for such a service).

The interference analysis has to be done on a pre-defined methodology, which has to be agreed upon by those included in the coordination process. To grant a licence that allows proper operation of the new system both checks have to be passed. This results in a first-come first served approach in which stations that are registered are protected from interference from stations that are deployed later.

Examples for systems where technical coordination is based on international agreements are for example FM sound broadcast systems that have been coordinated following the Geneva 84 Plan[64] or for DVB-T systems that used the Chester 97 agreement[65]. However, with RRC-06 the situation has changed. The final acts now define methods to determine radio stations that have to be included into coordination but don't define the coordination procedure itself. So it is very likely that in future coordination in the area of broadcast will be done on bi-lateral agreements that have to be agreed between different countries.

[63] "Satellite System Compatibility Analysis" Rajesh Mehrotra, ITU; BR Seminar Geneva, 2006

[64] "Final Acts of the Regional Administrative Conference for the Planning of VHF Sound Broadcasting (Region 1 and Part of Region 3)" Geneva 1984

[65] "The Chester 1997 Multilateral Coordination Agreement relating to Technical Criteria, Coordination Principles and Procedures for the introduction of Terrestrial Digital Video Broadcasting (DVB-T), CEPT, Chester, 25 July 1997

Another area where international agreements are used for coordination is the field of satellite communication. Besides the methods to be used to determine affected radio stations (like the dT/T method or the coordination arc approach), detailed methods for interference calculations are also laid down in recommendations like ITU-R S.740[66] and ITU-R S.741[67]. Initially, technical coordination is the task of the national regulatory authorities, but a common approach is to involve the operators in the coordination process or leave the coordination work completely to the operators. In the latter case the coordination results have to be approved by the regulator.

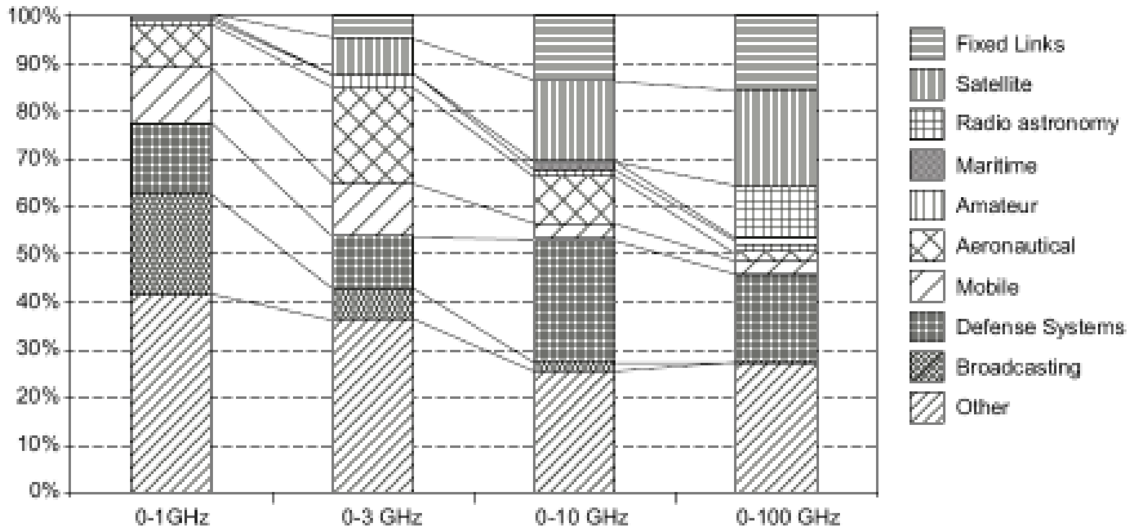
[66] "Technical coordination methods for fixed satellite networks" Rec. ITU-R S.740

[67] "Carrier-to-interference calculations between networks in the fixed- satellite service". Rec. ITU-R S.741

G. Case Studies on tightening Receiver Characteristics

G.1 Determination of Systems for Analysis

The following chart displays an analysis of the European frequency allocation table[68] where the band usage for different application types have been analysed. The applications given in the frequency table have been grouped together. An example is the category "Mobile" that includes applications like PMR/PAMR, GSM, GSM-R, IMT2000/UMTS and Land Mobile. Each bar in the chart spans a frequency range from 9 kHz up to the frequency indicated in the chart. The differently shaded parts of each bar indicate the fraction of spectrum allocated to a specific applications group. Several parts of the spectrum have been allocated to more than one service. An example is the band up to 1 GHz where approximately 2.4 GHz have been allocated to different applications. The 100% in the chart relates to this totally allocated spectrum for each analysed frequency range.



An analysis of the chart indicates that the largest block in the band below 1 GHz is allocated to the group "other" which includes several different applications. The second largest block is broadcasting, while defence systems and mobile services also utilize large blocks. In the higher bands fixed networks are allocated a lager fraction of bandwidth. Defence systems and aeronautical systems have not been considered since they consist of several different technical applications. Satellite systems have not been included in the analysis either, due to the global dimension of satellite services and the implications outside the EU which are not covered by this study.

From the identified application groups the following scenarios have been selected for further analysis:

1. Digital cellular mobile - 3G
2. Digital cellular mobile - GSM
3. Digital fixed radio systems

[68] http://www.efis.dk

4. Digital TV Broadcasting Networks (DVB-T).

G.2 Economic Approach

Cost-benefit analysis classically uses the concepts of consumer and supplier surplus to determine which solution to a policy problem would result in the greatest economic benefits. However, even a thorough analysis based on sound classical economic principles may not necessarily capture all the benefits accruing from a particular solution. For example, additional benefits of the following types may accrue:

- **Externalities**. Perhaps the most classic example of a cost externality is traffic congestion - each vehicle on a congested road contributes to the delay experienced by all vehicles, yet no compensation is paid by one set of vehicle occupants to all others (or vice versa). Congestion charging is aimed at correcting this problem. Externalities can result in benefits.
- **Economic stimulus.** In the telecoms sector studies have revealed a multiplier effect from telecom usage - the greater the use, the more GDP across a broad range of other sectors is also stimulated. For example, in the developed world good telecommunications services in remote areas enables IT jobs to be created in remote regions, and in the developing world telecoms enables farmers to enquire about market conditions before harvesting and taking produce to market.
- **Network effect.** The more subscribers are attached to the network, the greater are the communication opportunities for all those connected - again no specific payments are made by existing customers to new customers - however it is worth noting that in commercially driven communications markets (as is the case across Europe today), network operators and service providers usually offer prices for mass market services such as mobile and fixed telephone with a price structure which prices connection below cost, but retrieves the loss through subsequent usage, thus simulating the net benefit to all through price signals.
- **Intangible benefits.** These may be very varied. Greater availability of communications may lead to greater social cohesion, greater sense of wellbeing through ease of communication with friends and family, etc. While such benefits cannot be quantified in financial terms, they are nevertheless very important.

In this study, we have not attempted to measure either externalities or intangible benefits. In a sense we have been lucky not to have to do so. As the results presented below will reveal, improving the performance of the systems studied is highly likely to result in a substantial net benefit in at least three of the four cases studied. Therefore it has not been necessary to resort to analysis of other sources of benefit. But it should not be forgotten that improving system performance so as to increase the capacity of very useful bands (e.g. TV and mobile bands) will very likely result in significant external and intangible benefits in addition to those estimated here.

Furthermore, classical cost-benefit analysis requires the ability to draw demand and supply curves with some certainty, but this is much more difficult to do in the fast-moving communications sector where market development is a function not only of price but also of technology diffusion and migration from older to newer technology platforms. This is why we have selected the "opportunity cost" method to evaluate the technological improvements which form part of the case studies. It is arguably a better approach than the classical consumer- and supplier-surplus method, in that it enables policy decisions to be taken based on tangible and robust cost-benefit considerations.

The worksteps in the cost-benefit analysis are tabulated below:

	Workstep	Approach	Analytic focus
1	Identify Applications to Analyse	We have focused on the major Radio Applications: mobile, broadcast, and fixed links. For each, we have selected those aspects of system design which could be considered for improvement, and analysed the likely results in terms of accommodating more users or freeing up spectrum for other uses. In doing this, we have built on technical studies undertaken by major bodies such as 3GPP, and interpreted the results of such research studies into implications for system capacity whilst maintaining performance characteristic.	Technical Analysis
2	For each Application, identify and quantify the benefits	Use the concept of "opportunity cost" to estimate the value of the expected improvement in spectrum efficiency resulting from each case analysed technically in step 1 above. For example, improving antenna performance in DVB could release spectrum for mobile use, which has a clearly recognised minimum economic value	Economic Analysis
3	For each Application, identify costs for each user	We analyse what costs would be incurred to make the technical change. In most of the cases selected improvements in portable consumer terminals are required, and since these have a relatively short in-service life, introducing and establishing a given technical improvement becomes fairly easily achievable	Economic Analysis
4	Report results and make Recommendations	Report results of above analysis - compare costs and benefits of different interference performance improvement cases. Recommend if the improvement is likely to result in a clear net benefit.	Economic and Technical Analysis

G.3 The Case for UMTS

Overview Digital Cellular Mobile

The cellular mobile market in Europe is currently dominated by two major cellular technologies: between them GSM and UMTS networks address a mass market for mobile voice and data communications.

The air interface technologies used are based on publicly available standards[69] developed and maintained by the Third Generation Partnership Project 3GPP. The systems operate in harmonized bands, the ECA[70] reserves in total 220 MHz for GSM and 345 MHz for IMT-2000/UMTS. However not all parts of this spectrum are currently licensed for these applications. Licences for cellular mobile systems are generally granted nation-wide on a block basis.

[69] Standards can be downloaded from the 3GPP website at http://www.3gpp.org.
[70] http://www.efis.dk

Interference in cellular mobile systems is mainly caused by the system itself; each operator manages the frequency use inside its frequency block on its own. While deep inside a country each operator has flexibility in managing its band, limitations may apply close to national borders where bi- or multilateral coordination agreements like the HCM[71] agreement apply to frequency use.

System technology and end user equipment are provided by various suppliers. It is hardly possible for the network operators to control which terminal types are used within their networks. It is therefore essential that interoperability between system technology and end user terminals is achieved by standardisation and proper terminal certification.

GSM and UMTS standards are under continuous development towards higher data-rates. Technologies such as High Speed Circuit Switched Data (HSCSD); General Packet Radio System (GPRS) and Enhanced Data-rates for GSM Evolution (EDGE) have pushed data-rates in GSM networks in downlink from 9.6 kb/s to 171.2 kb/s (GPRS) and 473.6 kb/s (EDGE).

In UMTS higher data rates of up to 14.4 Mb/s (Downlink) and 5.76 Mb/s (Uplink) have been made available by the introduction of High Speed Packet Access (HSPA) in Release 5 and Release 6 of the UMTS specifications.

All technologies have in common that they make use of improved modulation schemes and adjusted air interface protocols to provide higher data-rates. However due to the more complex modulation schemes higher requirements in terms of required signal strength and allowed interference levels also apply which in turn will require a better radio environment.

Revenues for operators arise from selling air interface capacity (air time) to customers. Thus it is a fundamental interest of each commercial mobile network operator to provide as much capacity in its network as technically and economically feasible. By means of frequency planning (GSM) or adjusting the Multiple Access Interference (UMTS) the operators thus try to achieve a compromise between network capacity and QoS.

It has therefore been of interest to the stakeholders in the mobile community to improve receiver performance in interfered environments. In the following we study scenarios for UMTS and GMS and analyze the benefits of improved receiver characteristics for mobile networks.

Background of the UMTS scenario

UMTS uses Wideband Code Division Multiple Access (W-CDMA) to provide speech and data services and multiple data rates in a cellular environment. Both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) can be used to separate uplink and downlink direction. UMTS operates with 5 MHz blocks, in the case of TDD a single block is required while for FDD two times 5 MHz are needed to operate a UMTS cell. Typically UMTS macro-cell networks are employed using UMTS FDD.

[71] "*Agreement between the Administrations of Austria, Belgium, the Czech Republic, Germany, France, Hungary, the Netherlands, Croatia, Italy, Liechtenstein, Lithuania, Luxembourg, Poland, Romania, the Slovak Republic, Slovenia and Switzerland on the co-ordination of frequencies between 29.7 MHz and 39.5 GHz for the fixed service and the land mobile service. (HCM Agreement)*", Vilnius, 12 October 2005

Each signal transmitted to a specific user within a UMTS cell uses the complete 5 MHz block allocated to this cell. In the likely case that several terminals operate at the same time in a specific cell, the signals belonging to the different terminals will be mixed up, as each transmission utilises the complete bandwidth at the same time. To separate signals for different users each signal is scrambled with an individual scrambling code; by re-doing this scrambling procedure with the same code as used at the transmitting end the wanted signal can be re-constructed from the signal mix on the air interface. The codes used have to be orthogonal, a specific mathematic characteristic required to allow signal separation by scrambling and de-scrambling operations.

UMTS applies a channel reuse of one; each cell of a network uses the same frequency block, separation between different cells is achieved by scrambling the signals before transmission with a cell specific scrambling code.

As all signals of all users are transmitted in the same bandwidth the intended signals will thus interfere with each other. Signals intended for other terminals in a cell are seen as thermal noise and this leads to an increase of the noise floor in the cell (noise rise). The noise rise will decrease the available carrier to noise ratio of a given link. This effect is called Multiple Access Interference (MAI) and is typical of CDMA networks that use rake receiver technology. The noise rise in a cell is also affected by signals transmitted in adjacent cells of the same network as each cell of the network uses the same frequency block.

The capacity of a UMTS cell is limited by the number of orthogonal codes that are available for scrambling the user signals. However due to MAI the cell capacity is also limited by interference. The more signals are transmitted, the higher the noise rise and the more transmit power for a specific link is required to achieve a given C/N (or more precisely Eb/No) and with this a wanted Quality of Service. If the noise rise approaches a limit or the transmit power limits of the used terminals or base stations are reached, no further links can be operated, and a limit for the cell capacity is reached.

The capacity limit due to interference is not a hard limit as it depends on several parameters. Some of these parameters can be defined by the network operator who thus can achieve a trade-off between cell capacity, cell size, and quality of services.

As MAI in UMTS networks directly reduces network capacity, an improvement of receiver performance in interfered environments is of great interest for the UMTS network operators and system vendors. In consequence improved receiver designs have been studied and analyzed in the last years. Two studies performed by the Technical Specification Group Radio Access Network of 3GPP, the standardization body for UMTS, have addressed methods to increase network capacity by using interference cancellation technologies at the mobile receiver:

- Feasibility study on the mitigation of the effect of the Common Pilot Channel (CPICH) interference at the User Equipment[72]
- Feasibility study on interference cancellation for UTRA FDD User Equipment[73]

The following sections give a short overview on these studies and their results.

[72] "*Feasibility study on the mitigation of the effect of the Common Pilot Channel (CPICH) interference at the User Equipment (Release 5)*" 3GPP TR 25.991 V5.1.0, 12.2002

[73] "*Feasibility study on interference cancellation for UTRA FDD User Equipment (UE) (Release 7)*" 3GPP TR 25.963 V7.0.0, 04.2007

Mitigation of Common Pilot Channel Interference

A UMTS cell uses different channel types to transmit payload and control information. One channel that is transmitted in the downlink of each cell is the common pilot channel CPICH. The CPICH does not carry any information but is used by the terminals to monitor and identify cells during cell search and in the handover process. As the CPICH has to be available over the complete cell area and also close to the cell borders of adjacent cells it is transmitted with a relatively large power.

The idea behind CPICH interference mitigation is to eliminate or reduce the impact of Multiple Access Interference MAI originating from the CPICH of the own or adjacent cells. Terminals that use CPICH cancellation will experience less interference and thus require less transmit power from the base station. This will decrease the total transmitted power in the cell and thus lead to increased cell capacity.

The study performed by 3GPP presents capacity simulations for voice and data transmissions, which have been performed by Intel, Nokia, Motorola and Telia. Reported capacity gains range from approx. 13.6% for voice, 16.2% for 64 kb/s data, and 20.6% for 144 kb/s data where the terminal is able to cancel the Pilots of six different cells. If the number of cancelled pilots is reduced to those cells with which the terminal is in soft handover the capacity gains are reduced to approx. 7-10%. A further reduction of these gains in realistic reception conditions is expected due to receiver impairments/imperfections.

The study did not recommend the standardisation of CPICH cancellation, as

> "There was general consensus that there are other approaches to improved UE performance, and each UE vendor should be free to choose its preferred approach to meet any new performance requirements."

Feasibility study on interference cancellation for UTRA FDD User Equipment (UE)

The feasibility study on interference cancellation for UTRA FDD user equipment assesses the feasibility of one-branch and two-branch interference cancellation technologies at UMTS terminals using High Speed Downlink Packet Access (HSDPA). The analyzed method considered receiver structures that uses Linear Minimum Mean Squared Error (LMMSE) equalizer at sub-chip level that does not only adjust to the channel response of the serving cell but also to the channel response matrices of the most significant interfering cells. In this way interference from users operating outside the serving cell can be reduced.

In the study different interference models and profiles for other-cell interference were developed and analyzed, and two network scenarios were defined, one based solely on HSDPA traffic (HSDPA-only), and the other based on a mixture of HSDPA and Rel. 99 voice traffic (HSDPA+R99). HSDPA throughput estimates were then developed using link level simulations.

The study reports results from simulations that have been performed by system suppliers including Ericsson, Fujitsu, Intel, Motorola, Nokia, Tensorcomm, Panasonic, AT&T, Agere, InterDigita, LG Electronics, and Marvell.

A significant gain in throughput primarily at or near the cell edge has been found from the simulations that have been performed over a wide range of range of operating conditions including such factors as transport format, network scenario, modulation, and channel model. In addition, a system level study was conducted that indicated that an improved receiver provided gains in coverage ranging from 20-55% for mildly dispersive channels, and 25-35% for heavily dispersive channels, depending of the user location inside the cell. A second system level study divided the users into two different groups depending on their handover states, where the first group collected users in soft handover (between cells), and the second group collected users in softer handover (between sectors of the same cell). The results of this second study indicate that a suitable receiver design will provide benefits for users in these two groups, increasing their throughput by slightly over 20%.

Analysis and Conclusion for the UMTS case

Based on the studies performed by the technical Specification Group Radio Access Network of 3GPP we assume that a possible capacity increase for UMTS FDD networks due to interference mitigation technologies at the user terminal will be in the range of 10% to 20%.

In the frequency bands below 2500 MHz identified by WARC-92 for IMT2000 two times 60 MHz in the bands 1920 MHz – 1980 MHz (for uplink) and 2110 MHz - 2170 MHz (for downlink) have been reserved for UMTS FDD[74]. Thus a capacity increase of 10% to 20% is equivalent to of one or two frequency blocks of 2x5 MHz paired spectrum.

However, we must inject an element of caution into these results. In Europe typically there are an average of 4 to 6 operators per country with licences for UMTS frequencies[75]. Each operator therefore owns only two or three frequency blocks of 2x5 MHz of paired spectrum. If we assume an operator that owns and uses three blocks of 2x5 MHz, the capacity gain achieved to allow freeing one frequency block would need to be approx. 30% which has not been realised by the analysed technologies. Nonetheless, there are still significant technical gains, which might be realised in terms of an additional carrier for larger operators.

G.4 The Case for GSM

Background of the GSM Scenario

GSM uses a combination of Time Division Multiplex Access (TDMA) and Frequency Division Multiplex Access (FDMA) to provide voice and data services in a cellular mobile environment. The capacity of a single cell depends on the number of carriers allocated to it. Each carrier assigned to a cell uses paired spectrum with 200 kHz for uplink and 200 kHz for downlink communication and is sub-divided into eight timeslots. Each timeslot provides an individual link for data or voice communication. Capacity enhancements can be achieved by adding additional carriers to a cell. The maximum capacity of a cell is hence limited either by the possible carriers that can be operated by the base station hardware or by the number of carriers that are available for this cell.

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[74] http://www.umtsworld.com/technology/frequencies.htm
[75] http://www.umtsworld.com/industry/contracts.htm

Typically an operator is licensed for a part of the GSM spectrum; during frequency planning these carriers are allocated to cells. As a network generally contains more cells than carriers, frequency reuse has to be applied. While increasing the network capacity additional carriers have to be added to cells, thus the frequency reuse has to be tightened which will in turn lead to an increase in the interference level. Thus network capacity will be limited by interference for heavily loaded GSM networks.

A set of techniques has therefore been considered by GSM operators, system vendors and other stakeholders of the GSM society to increase the capacity of the GSM networks. Some of these techniques are related to the improvements or modifications of the network configuration (e.g. optimized frequency planning and site configurations) while others are related to the performance of the mobile station (MS). One technology that focuses on the performance of the mobile station is referred to as single-antenna interference cancellation (SAIC). SAIC is a generic name for techniques that use signal processing to cancel or suppress interference without the use of multiple antennas and thus allow an increase in the downlink spectral efficiency of GSM networks by modifying the user terminals.

The performance of SAIC has been studied within 3GPP where the issue was introduced at the beginning of 2002. A feasibility study, which was finished in mid-2004, showed the benefits of SAIC; contributors to the study included system vendors such as Ericsson, Motorola, Nokia, Philips and Siemens, and the operator Cingular Wireless which performed tests in its networks in Savannah and Delaware. The results of the study were presented in the report "Feasibility Study on Single Antenna Interference Cancellation (SAIC) for GSM networks (Release 6)"[76] where the effect of applying SAIC on the interference pattern encountered in real-life GSM networks has been documented.

The summary of the 3GPP feasibility study indicates that SAIC increases the performance of interference limited mobile terminals by several dB, measured in terms of the C/I required to meet a given QoS. Also non-SAIC terminals will benefit from SAIC as the improved link performance of the SAIC terminals will lead to generally lower interference levels due to power control mechanisms. Due to the increased performance of terminals using SAIC the network capacity could increase in the case that a high penetration rate of SAIC-enabled terminals is reached. Results achieved in the Cingular Wireless field tests indicate capacity increases by 60% to 100% when SAIC capable terminals only are used.[77]

Based on the results of the SAIC study standardization work for Downlink Advanced Receiver Performance (DARP) was been done and implemented in early 2005. DARP is an integral part of GSM Rel-6 and has also been made available as a release-independent feature for previously defined GSM standards (R99, Rel-4, and Rel-5).

DARP results in adapted receiver reference performance tables for SAIC-capable terminals in 3GPP TS 45.005 (radio transmission and reception) for potentially all voice and data services, new test setups including combined interference environments including co- and adjacent channel interference and associated performance requirements. Also new signalling methods have been defined to enable a handset to inform the network about its SAIC capabilities.[78]

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[76] "*Feasibility Study on Single Antenna Interference Cancellation (SAIC) for GSM networks (Release 6)*" 3GPP TR 45.903 V6.0.1 (2004-11).

[77] "*SAIC helps combat interference*" Carsten Pedersen and Zoran Zvonar, Analog Devices Inc. Aug 16, 2005. URL: http://www.commsdesign.com/showArticle.jhtml?articleID=168600379

[78] "*Overview of 3GPP Release 6 Summary of all Release 6 Features*" Version TSG #33 http://www.3gpp.org

Chipsets including SAIC for mobile phones are available from different vendors[79],[80] and mobile phones featuring SAIC have been available since the beginning of 2005[81].

Clearly the improvements in receiver performance due to the introduction of SAIC terminals can be used in different ways. One possibility is to increase the capacity of an already existing network to provide services to a larger number of users. This has been demonstrated in the study performed by 3GPP and obviously this is the main objective of network operators wishing to increase the capacity of their networks.

However, another way to benefit from the decreased C/N requirement would be to free a part of the spectrum to be used by other services. This scenario is analyzed in more detail in the following section.

Analysis of the GSM case

The scope of the analysis has been to determine the amount of spectrum that could be freed due to the improvements in receiver performance in interfered environments. The range of possible C/I improvement has been set based on the gains reported in the 3GPP SAIC study which lists gains in the range of 1 dB to 3.5 dB that can be achieved by SAIC technology. Based on these results the range for C/I improvements for the simulations has been set to 1 dB, 2 dB and 3 dB.

Simulations have been performed for the following network scenarios :

- Scenario 1 is characterized by a medium large city that is surrounded by rural areas in almost flat terrain.
- Scenario 2 is similar to scenario 1 except that on one side of the city the terrain rises, and base stations on top of the hills interfere with the base stations inside the city.
- Scenario 3 is characterized by a medium large city in difficult hilly terrain
- Scenario 4: A large city in almost flat terrain, surrounded by hills

The following table lists the key parameters of the analyzed networks:

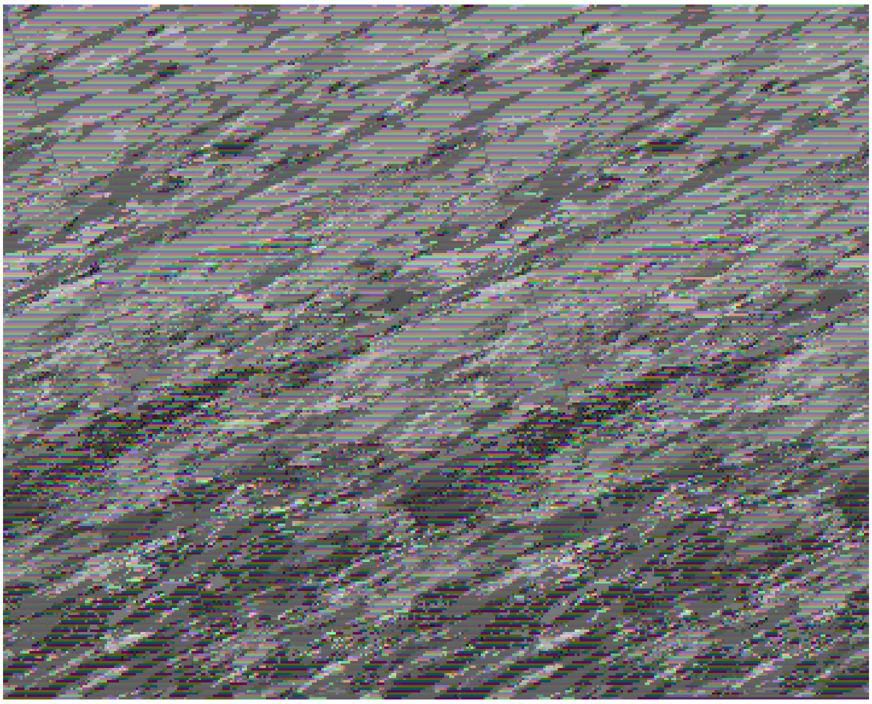
[79] "*New Infineon Mobile Phone Chip sets New Industry Standard for Ultra Low-Cost Handsets*" Press Release Infineon technologies, 13.02.2006, http://www.presseagentur.com/infineon/detail.php?pr_id=782&lang=en

[80] "Broadcom's Revolutionary M-Stream Technology Delivers Vastly Superior Voice Quality in Upcoming Palm(R) Treo(TM) 680" 17.11.2006. http://plusmo.com/start/preview.shtml?pid=558794

[81] Nokia press release, 06.2005: http://www.nokia.de/de/pressemitteilungen/nokiade/2005/06/168584-framedPopup.html

Scenario		1	2	3	4
Sites / Sectors		27 / 79	46 / 134	150 / 436	233 / 660
Cell Areas (km²)	Min	1	1	0.2	0.2
	max	24.21	24.21	13.57	48.67
	average	2.28	4.13	2.58	3.64
Antenna Heights (m)	min	25	17	10	10
	max	60	60	60	60
	average	26.80	26.18	25.55	25.71
Terrain Height above Sea Level (m)	min	102	98	199	434
	max	126	375	543	738
	average	114	127	360	539
Total Area of Scenario (km²)		36	588	1236	2799

The following picture illustrates the network of Scenario 4:

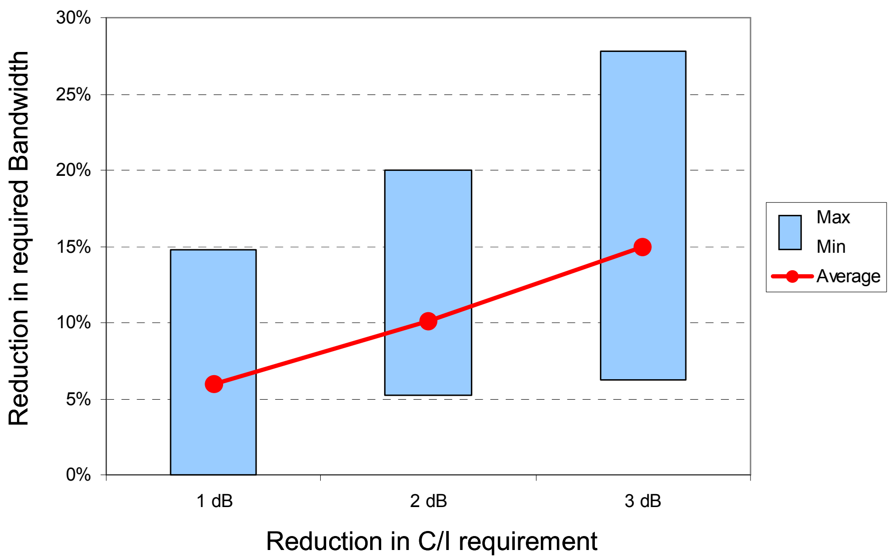


As benchmark for the carrier requirement the lower bound for the frequency assignment problem based on a binary constraints model has been used. For this interference probability matrices for the network scenarios have been computed for the C/I requirements and transformed into undirected graphs for different levels of allowed overall interference probability. Inside such a graph each carrier requirement is represented by a vertex, edges between vertexes represents relations between interfering carrier requirements. For each graph the largest complete subgraph has been determined. The number of vertexes inside the largest subgraph for a network determines the amount of required carriers, thus this figure can be used as lower bound for the frequency assignment problem.

The following table summarizes the key parameter of the simulations:

System Technology	GSM
Propagation Model for Field Strength Calculations	Cost 231 Okumura Hata
Terrain Data	Landuse- and Digital Terrain model
Fading Simulation	6 dB Standard deviation
Determination of Serving Cells	Assignment probabilities
C/I criteria	9 dB (Base Case), 8 dB, 7 dB, 6 dB
Allowed Interference Probability in Network	1%, 2%, 3%, 4%, 5%
Allocation Benchmark	Lower Bound / Number of vertexes in largest subgraph found for network

In the following chart the results from the different scenarios are summarized:



Each bar gives the variation of the bandwidth reduction over all scenarios in the cases where the initial C/I requirement is lowered by 1 dB, 2 dB or 3 dB. The red line gives the average over these values. For a reduction in C/I requirement the bandwidth reductions ranges from 0% to 15%, for 2 dB from 5% to 20%. For 3 dB reductions in bandwidth requirement of up to 25% are found. However the red line for the average is found in the lower half of the bars, indicating that only few scenarios reach the maximum shown reductions.

Conclusion for the GSM case

From the chart we conclude that a range from 5% to 15% of reduction in required bandwidth is reasonable corresponding to improvements of 1 dB to 3 dB in C/I at the handset.

G.5 The case for Digital Fixed Radio Systems

Overview

Digital Fixed Radio Systems (DFRS) are used to transmit data between fixed locations. Typically DFRS are implemented by line of sight microwave links that offer high capacities and high reliability. In total approximately 36 GHz of bandwidth is allocated to fixed links in the frequency range of up to 100 GHz.

Microwave links in frequencies above 1 GHz uses highly directive antennas and thus achieve a good decoupling between adjacent links. Due to the fixed installation of both the transmitter and the receiver and the use of antennas that provide a high cross polarization decoupling, very high capacities of the air interface are obtained. Typical frequency bands are 5 GHz, 7 GHz and 15 GHz for long haul links over distances up to 200 km while frequency bands above 20 GHz are used for shorter links from 1 to 20 km.

There are no specific standards for fixed link air interfaces, as is the case in mobile communications. Interoperability on the air interface between equipment of different system suppliers is not required as the same supplier provides the equipment at both ends of the link. On the baseband side the equipment typically provides standardized interfaces to connect to user systems such as ITU-T G.703, ITU-T G.957 or Ethernet 10/100BaseT(x) to connect to other communication equipment. However, even if no general standards for air interface technology of microwave links exist, there is a set of European Standards such as the ETSI EN 302 217[82] series that describes minimum requirements for a large set of air interface parameters and other technical parameters.

Licensing of Digital Fixed Radio Systems is typically done either as block licence or on a link-by-link basis. The first case is for example found where a larger operator gets a part of a microwave band for its unique use. Major operators of microwave links include mobile network operators that use a large number of microwave links in their fixed access networks to interconnect the base stations, and fixed network operators, within both core and access networks. The licensing per link is found for example where a company wants to operate links to interconnect different company buildings or plants.

Scenario Background and Analysis

The aim of the analysis has been to evaluate to what extent an improvement in receiver technology for microwave links would have a positive impact on the frequency usage requirements of a complex microwave network. Possible reduction in spectrum requirement of such an improvement could be used to

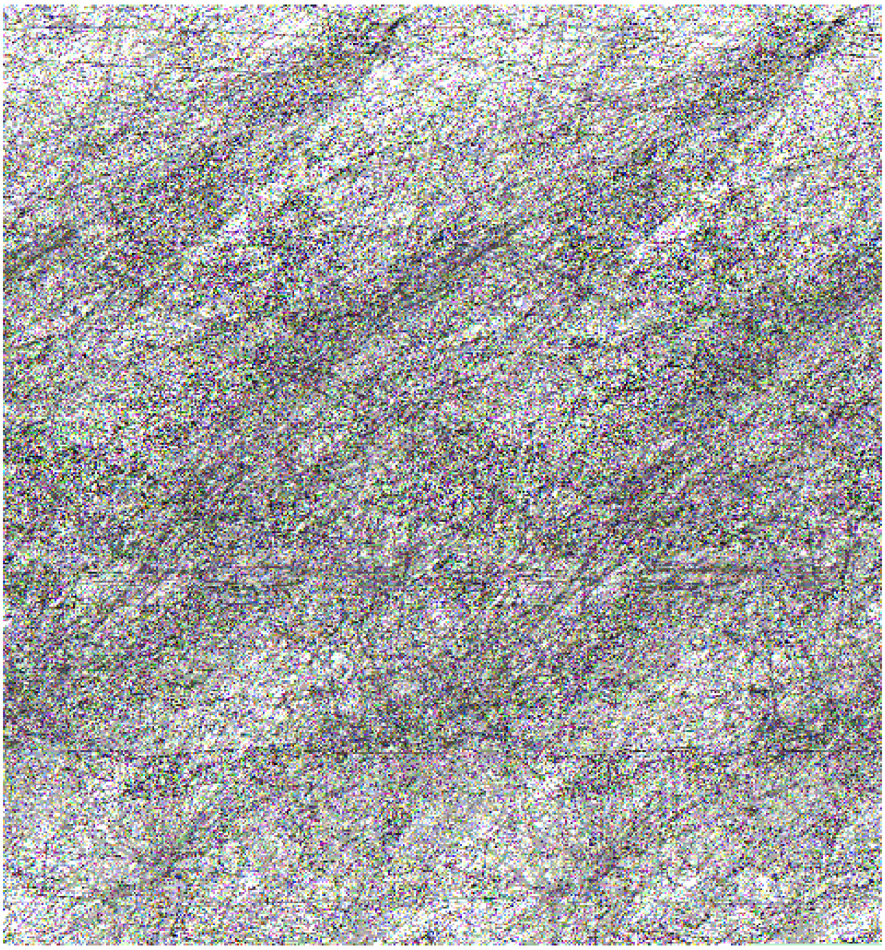
- implement further microwave links in a band that already is largely occupied by a dense network of microwave links
- increase the capacity on existing links
- make the released spectrum available to other radio services
- use the improved receiver technology to allow for shared band usage.

The improvement in receiver performance has been analysed based on a reduction of the carrier to interference ratio C/I required to achieve a given data-rate and Quality of Service. The examinations have been performed for a microwave network with in total 4900 links in the frequency bands 7 GHz, 13 GHz, 18 GHz and 23 GHz. The following table gives an overview on the analysed bands and the assumed base-line parameters for the links:

Frequency Band	Number of Links	Length of Links	Average link length	Required C/I
7 GHz	1050	4 to150 km	33 km	23 dB
13 GHz	550	2 to 52 km	15 km	27 dB
18 GHz	2000	1 to 40 km	8 km	27 dB
23 GHz	1300	0.4 to 16 km	4 km	27 dB

82 E.G. "*Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 1: Overview and system-independent common characteristics*" ETSI EN 302 217-1 V1.2.1 (2007-06)

The following picture gives an overview on a part of the analyzed network; the different colours for the links indicate the different frequency bands.



Initial C/I reductions have been set to –3 dB and –6 dB. As benchmark for the interference reduction the number of interfering links at a target link and the number of channels that possibly could be released have been used. The results for this analysis are in the table below:

Frequency Band	Number of allocated Channels	Reduction of Interference Relations		Released Channels	
		-3 dB	-6 dB	-3 dB	-6 dB
7 GHz	20	14 %	28 %	0	1
13 GHz	8	14 %	29 %	0	1
18 GHz	17	14 %	28%	0	1
23 GHz	41	22%	44%	0	2

From the initial analysis it can be seen that even with relatively large improvements in required C/I a rather small effect is found; so more detailed analyses have not been performed. A reason for the limited reduction might be found in the high directivity of microwave antennas, the line-of-sight environment, and the densely packed frequency band where links either interfere at a very high level or do not interfere at all.

Further limitations for the reduction of microwave spectrum might be found in the way links are planned and implemented. In most cases microwave links are planned and operated with a high fade margin that allows for fading losses due to rain and other irregular attenuation effects. This leads to high transmit powers that on the one hand will increase the reliability of the link, but on the other hand will increase interference in the network. For 95% or more of the time such high transmit powers are not needed. Typical fade margins are in a range from 20 dB to 35 dB.

To minimize interference due to high transmit powers recent microwave equipment employs automatic transmit power control (ATPC) where the transmit power is automatically adjusted to the lowest level required to operate the link with satisfactory quality. However elderly equipment does not have ATPC and thus operates with a constant high power level.

The effect of using ATPC is illustrated in the table below that shows two analyses where the ATPC control range has set to 10 dB and 20 dB. In both cases a significant result in spectrum reduction can be seen:

Frequency Band	Number of allocated Channels	Reduction of Interference Relations		Released Channels	
		10 dB	20 dB	10 dB	20 dB
7 GHz	20	26 %	51 %	1	6
13 GHz	8	34 %	45 %	3	4
18 GHz	17	40 %	63 %	2	4
23 GHz	41	43 %	66 %	5	7

Conclusion

The analysis has shown that a reduction in C/I requirements of up to –6 dB does not lead to a considerable effect in terms of freed spectrum.

A better result could be achieved by the introduction of automatic transmit power control, which allows transmitted powers to be reduced, on average, by 10 to 20 dB and thus would reduce the interference in the network. Such a technique does not represent any change in receiver characteristics, but instead suggests that there may be other mechanisms which are equally, or more, beneficial.

G.6 The Broadcasting Case (DVB-T)

Overview

DVB-T stands for Digital Video Broadcasting – Terrestrial and is a standard developed by the DVB European consortium and standardized by ETSI. DVB-T provides digital television broadcast by terrestrial transmitters. Currently DVB-T is being implemented throughout Europe and will replace the analogue television systems by the end of 2015. Enhancements to the DVB-T standard are currently planned.

DVB-T and DVB-H use OFDM (Orthogonal Frequency Division Multiplex) modulation and offer a set of technical parameters that make it a very flexible system. Transmit modes with different parameters for the air interface including modulation scheme, guard intervals and method of error protection allow the operator to find a suitable trade-off between bit rate and robustness of the transmitted signal. The use of OFDM modulation in combination with appropriate guard intervals allows the operation of DVB-T as single frequency networks (SFN). In an SFN several transmitter uses the same frequency within the same geographic area to achieve the required coverage[83] [84].

Frequency plans for DVB-T in bands 174 – 230 MHz (VHF Band with 7 MHz and 8 MHz channel spacing) and 470 – 862 MHz (UHF Band with 8 MHz channel spacing) have been developed and were finally agreed between 101 administrations at a regional radiocommunications conference for parts of ITU regions 1 and 3 in 2006 (RRC-06)[85]. The preparation work for RRC-06 was carried out over several years and included a preparatory conference in 2004 (RRC-04). Different reception modes have been defined and considered for the coordination calculations in RRC-06.

The administrations involved in the coordination procedures submitted their frequency requirements for DVB-T either for single transmitters (assignments) or for regions (allotments). Where country requirements have been submitted as allotments, these allotments have been defined in different layers where each layer covers the entire country and is subdivided into smaller non-overlapping regions. These regions have been defined based on regional coverage requirements as well as on technical necessities. Frequency planning and coordination over regions within one layer and over the regions of different layers has been done in a way that interference between regions belonging to one layer and interferences between different layers have been avoided. In the UHF band seven different layers have been defined, that in total comprise 49 channels with a bandwidth of 8 MHz for each channel.

Scenario Background

For the plans agreed at RRC-06, the DVB-T system was planned for a number of different reference planning configurations (RPCs) that included different reception modes, namely, fixed reception, portable (outdoor and indoor) reception and mobile reception, using a number of appropriate system variants and location probabilities[86]. References to antenna diversity for receivers are not found in the RRC-06; however the final document for RRC-04 refers to the potential benefit of diversity technology:

[83] DVB Fact sheet, DVB Consortium, April 2007. www.dvb.org

[84] "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television" ETSI EN 300 744 V1.5.1 (2004-11)

[85] "Final acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)", ITU Geneva 2006.

[86] Annex 3.5 of "Final acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)", ITU, Geneva 2006.

> Antenna diversity is a key technique for future mobile DVB-T compliant broadband multimedia receivers. The potential advantages of using antenna diversity for mobile reception are considerable, since for low-speed mobile reception a 6 to 8 dB gain in C/N values is expected. This should lead to improved robustness against variations in reception conditions. For planning purposes, antenna diversity is not taken into account.
>
> *Section 3.3.3 of RRC-04 resolutions*[87]

The goal of the analysis performed as part of this study was thus to determine what benefits could be achieved if receivers with antenna diversity were made mandatory.

In principle the implementation of antenna diversity technology at the receivers of a DVB-T system will bring a general system gain that will allow for one of the following:

- Increase the coverage area per transmitter while keeping the transmit power constant
- Reduce the transmit power for a transmitter while keeping the coverage area constant
- Increase the data throughput while keeping the coverage area and the spectrum requirement constant
- Improve the coverage provided by a given network (e.g. for indoor coverage or for vehicular coverage at higher speeds).

These different cases will be discussed in more detail in the following sections.

Increase the coverage area per transmitter

Antenna diversity gain can be used to increase the area that can be covered by a transmitter while keeping the transmit power of the transmitter constant compared to the case for networks planned for receivers without diversity. For a given area this might lead to a smaller number of transmitters required to cover the area when a network deployment is planned from the start for user terminals with antenna diversity. However as DVB-T networks very often are implemented as single frequency networks (SFN) where several transmitters are operating with the same frequency a reduction in the number of transmitter might not directly lead to a decrease in required spectrum.

Reduce the transmit power per transmitter

A diversity receiver will require on average lower field strength levels than a receiver without diversity. The requirement to use only receivers with diversity would therefore allow reduction of the transmit powers in a DVB-T network that has been initially planned without taking diversity technology into account. In the likely case of a single frequency network (SFN) the reduced transmit power will not reduce the required spectrum, however interferences to other services in the vicinity of the DVB-T network will be smaller due to the reduction in emitted power.

[87]: "Resolutions of the First Session of the Regional Radiocommunications Conference for planning of the digital terrestrial broadcasting service in part of Region 1 and 3, in the Frequency bands 174-230 MHz and 470-862 MHz" ITU, Geneva, 10-28 May 2004

Increase the data throughput
The DVB-T standard offers the operator the possibility to select from different transmission modulation schemes. These modulation schemes differ in their carrier-to-noise (C/N) requirements to achieve a given quality of service but also offer different data throughputs; in principle it can be said that higher order modulation schemes offer increased data throughput at the cost of increased C/N requirements.

Where the gain due to diversity reception exceeds the differences in C/N requirements for different modulation schemes the gain could be used to switch to a less robust but more spectrum efficient modulation scheme. In this case a higher data throughput within the same part of the spectrum could be achieved or a part of the spectrum could be freed as the same content as before could now be transmitted over a smaller part of the spectrum.

Improvement of the coverage for an existing network
The gain in required C/N due to diversity technology can also be used to improve the coverage situation in networks that have been planned for receivers without diversity. This could for example comprise the provision of better indoor coverage in areas where, after network deployment, poor coverage has been identified and thus a gap filler would be required to increase coverage. Diversity reception could therefore be used to avoid the installation of further gap filling transmitters. However in the case of SFNs this will not lead to reduction in spectrum requirements.

From the above mentioned possibilities to make use of a potential gain due to diversity technology, the option to increase the data throughput seems to be the one that would provide the largest effect in terms of savings of spectrum usage. This case has therefore been further analyzed.

Analysis

The following assumptions have been used during the analysis where values for DVB-T have been adapted to parameters typically used in the German DVB-T deployment:

- UHF Frequency band from 470 MHz (Channel 21) to 862 MHz (Channel 69)
- Channel width of 8 MHz
- Initial Modulation Scheme 16-QAM 2/3 with guard Interval ¼
- A gain of 6 dB to 8 dB is given in the RRC-04[88] document; the analysis has been done for a gain of 6 dB.

The basis for the analysis has been the different C/N requirements that are given for the possible modulation schemes within the DVB-T system. The table below has been extracted from the RRC-06 document[89] and gives an overview on the possible modulation schemes, the corresponding C/N requirements and the available net bit rates. The same values are also found in Table A.1 of the relevant ETSI Standard for DVB[90].

[88] Section 3.3.3 of Chapter 3 of Annex to RRC-04 final resolutions: "*Resolutions of the First Session of the Regional Radiocommunications Conference for planning of the digital terrestrial broadcasting service in part of Region 1 and 3, in the Frequency bands 174-230 MHz and 470-862 MHz*"; ITU, Geneva, 10-28 May 2004

[89] Table A.3.1.1 of *„FINAL ACTS of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)*"ITU, Geneva, 2006

[90] "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television" ETSI EN 300 744 V1.5.1 November 2004.

8 MHz variants						
			Net bit rate (Mb/s) for different guard intervals (GI)			
Modulation	Coderate	C/N min (dB)	GI= 1/4	GI=1/8	GI=1/16	GI=1/32
QPSK	½	13,0	4.98	5.53	5.85	6.03
QPSK	2/3	16,0	6.64	7.37	7.81	8.04
16-QAM	½	18,5	9.95	11.06	11.71	12.06
16-QAM	2/3	21,5	13.27	14.75	15.61	16.09
64-QAM	½	23,5	14.93	16.59	17.56	18.10
64-QAM	2/3	27,5	19.91	22.12	23.42	24.13

The above table shows that an improvement of the C/N requirement by 6 dB will allow for an increase in the net bit rate of between 5 Mb/s and 8 Mb/s depending on the initial modulation scheme and the guard intervals used. Under the assumption of typical values like those used in DVB-T deployments (16-QAM with a code-rate of 2/3 and a guard interval of ¼) a switchover to 64-QAM with code-rate 2/3 could be achieved while maintaining the same coverage. This would lead to an increase of 6.6 Mb/s (50%) in the provided net bit rate.

The increase in net bit rate would allow the transmission of two additional programmes per RF-channel without reduction in the transmit quality of the existing programmes. With the initial configuration without diversity gain each RF-Carrier can be used to transmit four different TV-programmes. If diversity receivers were imposed, 6 further programmes would be possible. If it were assumed that the available 49 channels are divided into 7 layers this would allow providing at each location on average 28 programmes without diversity or 42 programmes with diversity.

Instead of increasing the number of programmes the increase in net data rate could also be used to free a part of the spectrum while offering the same number of programmes. With the initially assumed parameters for reception without diversity at each location 7 layer are required that provide 28 programmes. When using the parameter related to reception with diversity this would allow provision of 30 programmes within 5 layers. Thus in maximum 2 Layers could be freed which would allow to release approx. 2/7 * 49 x 8MHz = 112MHz of spectrum that is currently allocated to DVB-T.

However to fully exploit this scenario, transmitter sharing would be required where different content providers would use the same transmitter and multiplex. The scenario also does not consider irregularities in the layer structure due to regional coverage requirements and specific propagation conditions which leads to higher spectrum requirements. The indicated 112 MHz can therefore be seen as a theoretical upper bound that can only be reached under idealistic assumptions. It is estimated that an average value of approximate 70% (78 MHz) is more realistic for DVB-T deployments over Europe.

Chipsets and DVB-T receivers with diversity reception are available. The approximate gain for 16 QAM CR2/3 and a guard interval of 1/8 are claimed to be in the range of 8 dB[91].

[91] Presentation "*Broadcast goes mobile – From DVB-T to DVB-H*"; Gerard Pousset, Workshop on mobile broadcasting, Brussels 23.02.2006,

Conclusion

As a result of the analysis, it has been found that the introduction of antenna diversity receivers will either allow an increase in the number of transmitted programmes by approx. 50 % or the release of approximately 78 MHz of spectrum provided different content providers share the same transmitters.

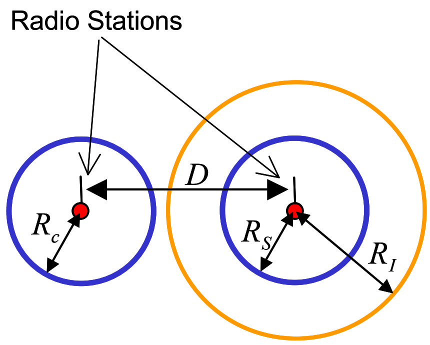
H. Sharing Spectrum

H.1 Analysis of Geographic Spectrum Sharing

To exactly model the effects of band usage over geographic borders, parameters such as topology, land use, implementation of radio station, frequency band and operated services have to be considered. However to evaluate the general mechanism a simpler model can be used based on two different areas that can be defined for each radio station:

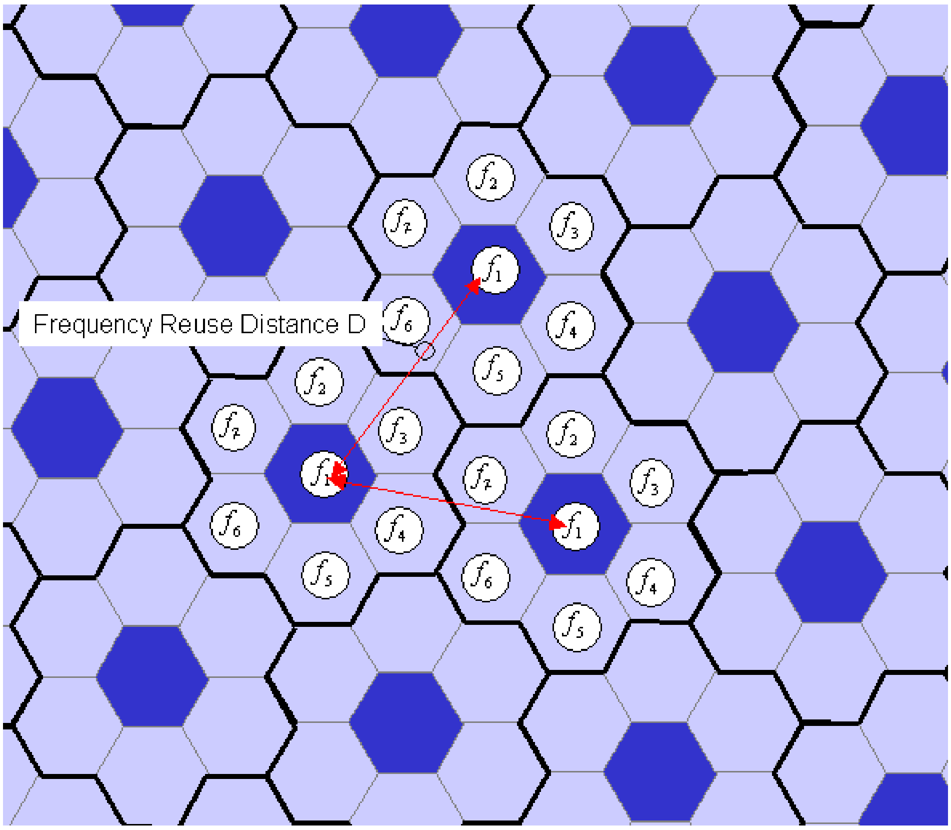
- The area in which the received signal strength from this radio station is sufficient to achieve a suitable quality of service. This area is called the service area; and
- The area in which the received signal strength from this radio station is sufficient to interfere with signals from other radio stations. This area will be called the interference area.

Under the assumption of homogenous propagation conditions these areas can be described by circles around the transmitter with radius R_S for the service area and R_i for the interfering area. To avoid interference between two radio stations operating the same frequency the spatial distance D between the two stations has to be selected in a way that there is no overlap between the service area of the one radio station and the interfering radio station of the other one:

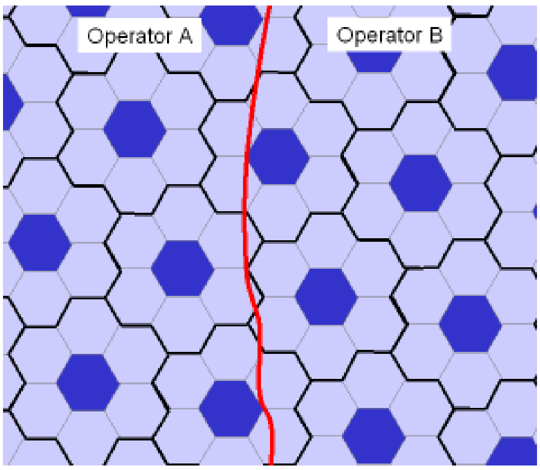


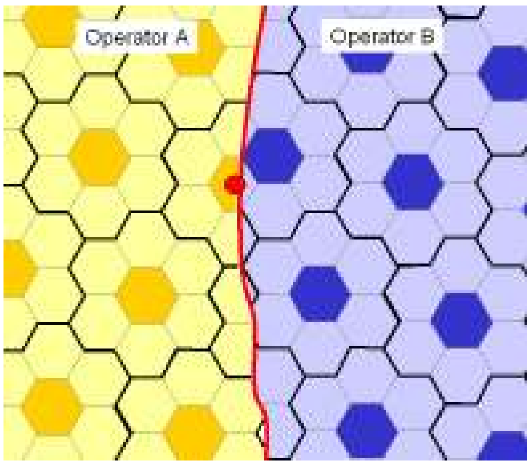
The distance D is called the reuse distance as it gives the minimum distance between radio stations that can use the same frequency.

If service is to be provided over larger areas several radio stations have to be implemented to provide this service. In case of homogenous propagation conditions such a deployment will result in homogenous site spacing, the service areas for a single radio transmitter can be displayed as a hexagon. Depending of the size of the service area and the reuse distance D a specific number of frequencies is required to allow un-interfered operation of such a set of radio stations. From the homogenous spacing of the radio stations originates a regular pattern of frequency reuse where radio stations that cannot use the same frequency are clustered together. The number of base stations in such a cluster is called the cluster size K. The following picture shows such a cluster with a size $K = 7$, the border of a cluster is marked as a bold line, the cell in the center of a cluster is marked with darker color:



Where the network is operated close to the border of the licence area this border will cross the regular pattern at arbitrary positions. If it is assumed that the operators on both sides of the border cooperate on radio planning, the regular cell pattern could continue and thus there would not be any impact of the licence area border (see picture below on the left side). However a scenario where each operator deploys its network regardless of the operator on the other side of the border is much more realistic (right side of the picture below):





In this case interference between operator A and operator B might occur if the same frequency band is used. If for example operator A uses a radio station at the location marked with a red dot in the picture above the spectrum allocated to this radio station cannot be used in a specific area A_{share} in the licence area of operator B and thus in this area only the fraction c of the total bandwidth B is available to operator B. With this and the definitions from above the sharing loss for the scenario is found as

$$L_{Sharing} = S \cdot (1-c) \cdot B \cdot A_{share} \quad (6)$$

and the sharing efficiency of the scenario can be expressed as

$$E_{sharing} = \frac{U_{sharing}}{U_{unshared}} = \frac{U_{unshared} - L_{sharing}}{U_{unshared}} = 1 - \frac{S \cdot (1-c) \cdot B \cdot A_{share}}{S \cdot B \cdot A_{licence}} = 1 - (1-c) \cdot \frac{A_{share}}{A_{licence}} \quad (7)$$

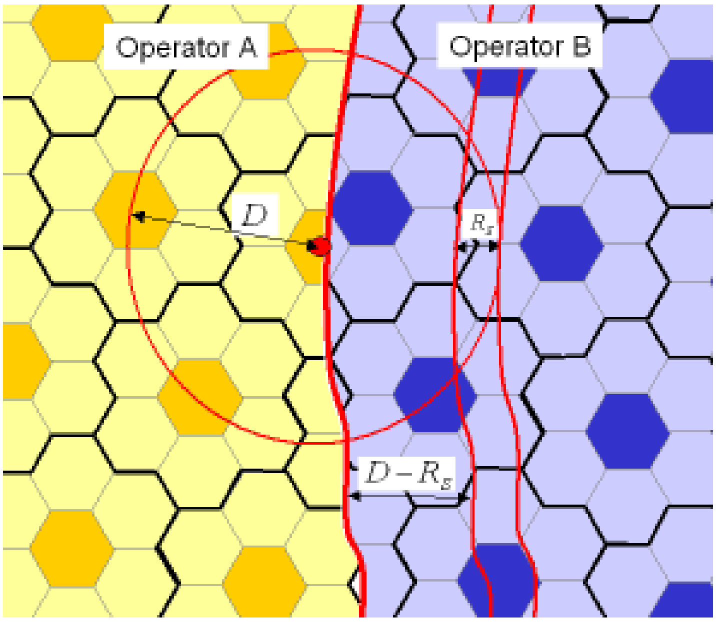
The possible range for $E_{sharing}$ can be immediately found from equation 7:

- The maximum found value for the sharing efficiency is one, in case that the complete bandwidth can be used in the total area $A_{licence}$ and thus A_{share} becomes zero. This is the case when the operators A and B coordinate their network planning.

- The minimal found value for the sharing efficiency is c in case that the entire licence area $A_{licence}$ is affected by the operator from the other side of the border.

Thus it is found that a single operator will always experience a loss in the case of unplanned band sharing over geographic borders. However this does not imply that geographic band sharing will always lead to an overall loss in spectrum use. If a scenario is considered where a licence area, which has been originally used by one operator, is split in two areas and one part is given to another operator, at the first moment each operator will experience a sharing loss due to band sharing. If both operators use technology with the same spectral system efficiency, a total loss over both areas is also experienced compared to the one operator case. However if the new operator uses technology with better spectral system efficiency this might outweigh the sharing losses so the spectrum usage inside the total area might increase even if each operator has a sharing loss.

To develop an estimate for the sharing efficiency the worst case for geographic sharing is considered. Under homogenous propagation conditions this is found if a radio station is located close or almost on the border:



If similar characteristics are assumed the same cluster size on either side of the border is found, and with this the area A_{share} can be defined by a circle with radius D around the location of the interfering station. Operator A might locate radio stations at any arbitrary point of the border and use any part of its frequency band. Thus the area in which operator B cannot run a radio station using the band that is also used by operator A will become a strip of width D along the border. With this the maximal zone where the band of operator A cannot be used by operator B will be found to be a strip of width $w_{share} = D - R_S$.

Where operator A places its stations in a way that the border of its service area falls on the border between the licence areas the distance between radio stations and the border will be approx. R_S and with this $w_{share} = D - 2 \cdot R_S$.

For large areas and simple border geometries an estimate for the affected area is the product of the length of the border L_{Border} where sharing is done and the strip width w_{share}, however for more realistic border lines and smaller licence areas this approximation will overestimate the affected area:

$$A_{share} = f_{Border}(L_{Border}, w_{share}) < L_{Border} \cdot w_{Share} \quad (8)$$

With this a range for A_{share} in dependence of the frequency reuse distance D and the radius of the service area R_s can be given:

$$f_{Border}(L_{Border}, D - 2 \cdot R_S) \leq A_{share} \leq f_{Border}(L_{Border}, D - R_S) \quad (9)$$

If the upper bound from (9) is inserted into (7) we will find an estimation that allows analyzing the sharing efficiency for different services, border lengths and area sizes:

$$E_{sharing} \leq 1 - (1 - c) \cdot \frac{f_{Border}(L_{Border,} D - R_s)}{A_{licence}} \quad (10)$$

Parameter range for simulations

To use equation 10 the range for the different parameters has to be selected. The following gives a short discussion of the possible range for each parameter and lists the values that have been used during the done analyses:

The factor c

The factor c gives the fraction of the Bandwidth B that is available in the affected Area A_{share} close to the border. Its value depends on the type band split done at the border. The typical case is that the band is split in two equal parts and thus a worst case of $c = 0.5$ will be found. Depending on the topography in the border region also higher values of c might be found if parts of the border strip are shadowed and thus allows un-interfered usage of the complete frequency band in a part of the border region. This can be modeled by an increased factor c. Where the same regulator controls both areas also an un-balanced split of bandwidth is thinkable (e.g. 0.7 / 0.3) to adjust the allocated bandwidth to the different needs of the operators.

For the analyses a range of 0.3 to 0.7 has been used.

The relation $f_{Border}(L_{Border}, w_{share})$

To perform the analysis some assumptions regarding the relation between border length L_{Border}, the strip size w_{share} and the affected Area A_{share} have to be taken. Yet, this relation strongly depends on the geometry of the selected licence region and cannot be calculated in a simple way. For basic geometrics a closed relation can be given for the first analysis a geometry based on squares has been used for which the relation $A_{share} = f_{Border}(L_{Border}, w_{share}) = L_{Border} \cdot w - w^2$ is found. This relation offers a more conservative result than the product of the border length and the strip width.

The border length L_{Border}

For the analyses it has been assumed that along the complete border of the analyzed licence area sharing is done and thus L_{Border} has been computed form the size of the licence area. In real scenarios a licence area is most likely adjacent to more that one other licence area. In this case in some regions there will be a sharing between 3 (or more) operators which will further limit the available bandwidth. During the following analysis this has not been considered, as the focus has been to yield an estimate for an upper bound for the sharing efficiency.

The radius of the service area for one radio station R_S

The radius of the service area depends of the provided service and the transmitter implementation. The following table gives an overview on typical ranges for different applications:

System	Typical Range for R_S
Digital PMR Cellular	3 – 15 km
Analogue PMR	10 – 20 km
Digital cellular mobile	1 – 10 km
Digital TV Broadcasting (DVB-T)	20 – 30 km
Analogue FM Sound broadcasting	20 – 40 km
Analogue TV broadcasting (UHF)	20 – 50 km
Point to Multipoint LOS (3.5 GHz)	10 – 20 km
Point to Multipoint NLOS (3.5 GHz)	1 – 2 km

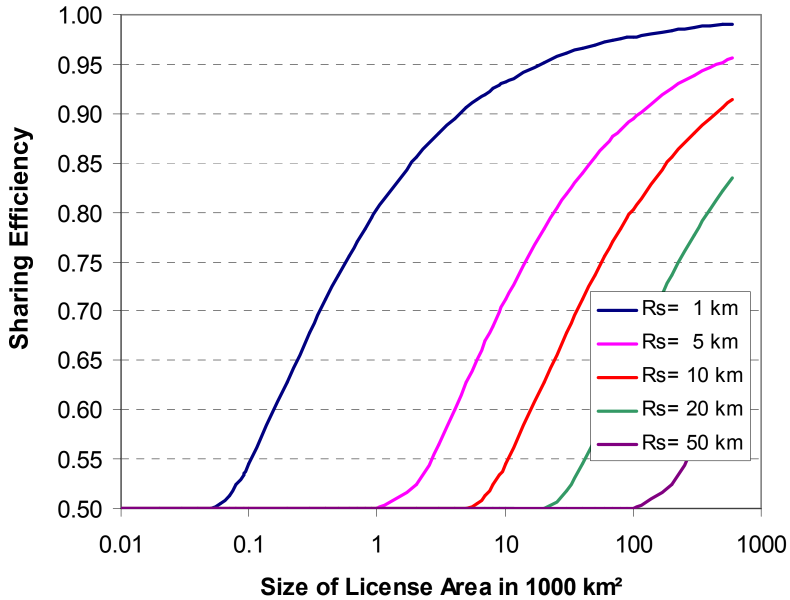
The analyses have been performed in a range of 1 km to 50 km for R_S

The frequency reused distance D

For hexagonal grids the fraction of frequency reuse distance D and the radius of the service area R_S can be given as function of the cluster size K: $D/R_S = \sqrt{3 \cdot K}$. For the analysis K has been selected in a range from 3 to 21 and with this values of 3 to 7.9 for D/R_S have been found.

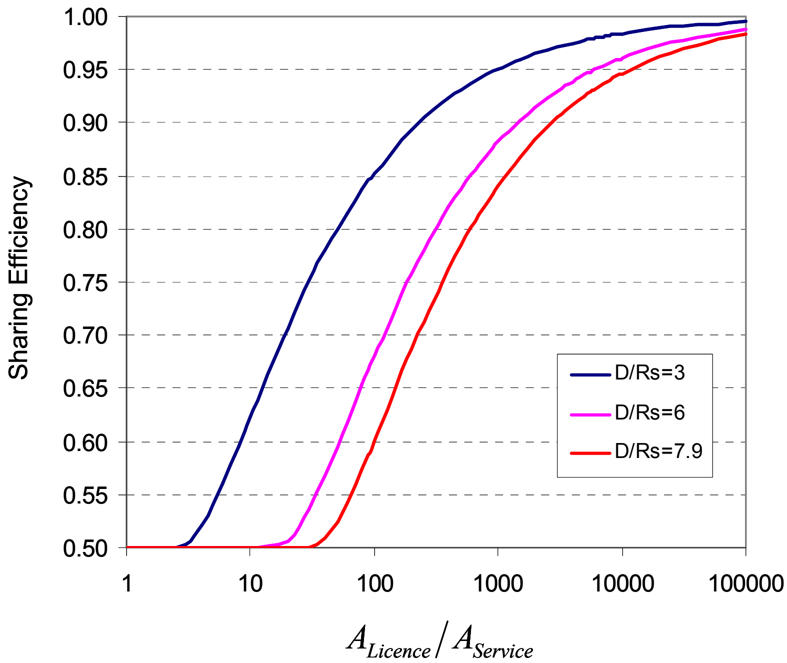
Results and Discussion

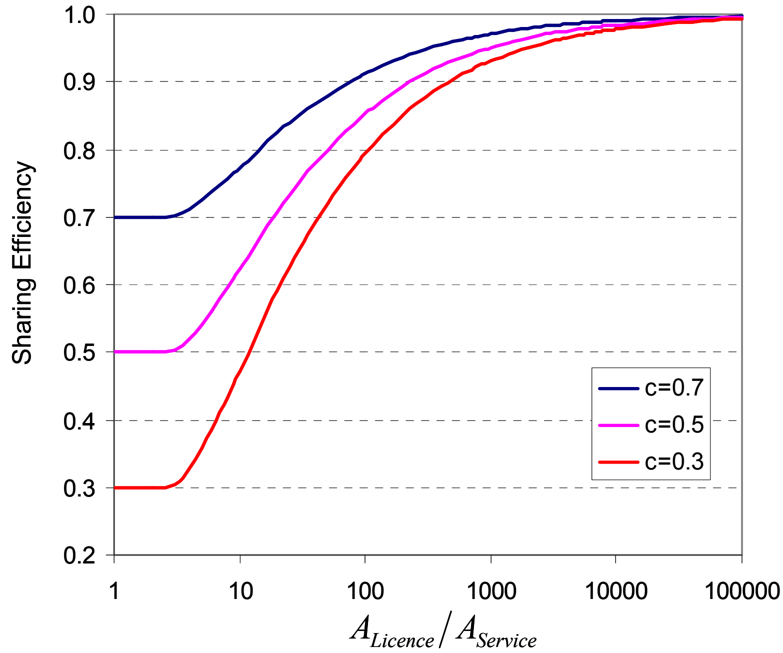
The following graph shows the sharing efficiency in dependence of the size of the licence area and the cell radius. The analysis has been done for $D/R_S = 4.5$ and $c = 0.5$:



A closer analysis shows that the curves for different service radius R_S become identical in case that they are drawn over the fraction of the size of the licence area $A_{licence}$ to the service area $A_{service}$. The fraction $A_{Licence}/A_{Service}$ can also be interpreted as an estimate for the number of radio stations that are needed to provide service over this area. This allows to determine how large a network has to be to achieve a effective spectrum usage.

In the following charts the variation of spectral efficiency due to changes in the frequency reuse distance (upper chart, $c = 0.5$) and due to changes in the fraction of available bandwidth c (lower chart, $D/R_S = 6$) are drawn in dependence of the fraction $A_{Licence}/A_{Service}$:





The charts allows to identify several general characteristics of geographic spectrum sharing:

- With decreasing size of the licence area the sharing efficiency will reach a lower bound which is given by the fraction of useable bandwidth c.
- The sharing efficiency depends on the size $A_{Licence}$ of the licence area and the size $A_{Service}$ of the service area of a single transmitter. The larger the fraction $A_{Licence}/A_{Service}$ the higher the sharing efficiency.
- The sharing efficiency depends on the frequency reuse distance D. The higher the fraction D/R_S the smaller the sharing efficiency for the same fraction $A_{Licence}/A_{Service}$.

- The fraction $A_{Licence}/A_{Service}$ can also be interpreted as an estimate for the number of radio stations that are needed to provide service over the total service area. Thus it is found that an effective usage (e.g. sharing efficiency > 80%) of the allocated band by an operator only can be achieved if the network reaches a relatively large size of several 100 to 1000 radio stations in any other case geographic sharing will lead to a sharing loss in case that the sharing is done in an unplanned way (which means $c < 1$).

H.2 In-Area Sharing Methods

The following section gives a short description of the in-area sharing methods listed in section 6.4.4 above:

Band sharing
In the case of band sharing the total bandwidth is split into several sub-bands; each sub-band is allocated to a different service or operator over the licence area. To avoid interference between services, guard bands between the different bands have to be defined. Due to the guard bands a part of the spectrum is lost and cannot be used for communications. Thus, if the spectral system efficiency of the different services is in the same range or even smaller than the efficiency of the initial system, a sharing loss will result, and the sharing efficiency will become less than one. A borderline case occurs where two operators uses the same service and coordinate their planning; in this case guard bands might be avoided and thus the sharing efficiency could become one. If one of the introduced services offers better spectral system efficiency than the initial service, a gain in spectrum usage might be found.

Geographic sharing
The sharing of frequency bands in adjacent geographic areas has been discussed in detail in earlier sections of this report. It has been found that geographic sharing between services will lead to a considerable sharing loss where the sharing is done in an uncoordinated way. However if an area is split in several sub-regions a total gain over all areas can be achieved where one of the used system technologies offers better spectral system efficiency than the service that has been operated over the total area. Thus the sharing loss in the border areas might be outweighed by a gain inside the areas of the improved technology.

Temporal sharing
Temporal sharing can be done at either an organizational or a technical level. While in the first case different services might use the same frequency band following a pre-defined schedule, in the latter case an automatic sharing is possible, where the operated systems automatically detect and utilize spectrum that is not used by other services. This assumes that not all services operate at all times. Under this assumption temporal sharing will always lead to a sharing gain as spectrum resources will be used that otherwise would have lain fallow.

Parallel spectrum sharing

Parallel spectrum sharing means that two different services operate at the same time, in the same geographic region and in the same frequency band. Such spectrum sharing requires specific technology that is both able to mitigate interference from other systems and will not itself cause interference. Systems that fulfil these requirements are for example spread spectrum systems or ultra wideband systems as they can mitigate interference from narrow band systems and only transmit with small power over large bandwidths. Parallel spectrum sharing is also possible for systems that use highly directive antennas and thus can suppress signals from given spatial areas. In both cases parallel spectrum sharing can increase spectrum use, although a certain amount of regulation or planning is required to avoid interference between services.