Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Inquiry Regarding Software Defined Radios	)	ET Docket No. 00-47
	)	
	)	

To: The Commission

COMMENTS OF BELLSOUTH ON SOFTWARE DEFINED RADIOS

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Dated: June 14, 2000

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COMMENTS OF BELLSOUTH ON SOFTWARE DEFINED RADIOS

BellSouth Corporation ("BellSouth") files these comments in response to the Commission's *Notice of Inquiry* concerning the current state of software defined radio ("SDR") technology and whether changes in applicable Commission rules are required to encourage implementation of this technology.[1] Attached to these comments are (1) a white paper discussing the development of software based radio (Attachment A), (2) responses to the Commission's specific questions (Attachment B), (3) definitions of relevant terms (Appendix A) and (4) illustrations of software radio concepts (Appendix B). In these comments, BellSouth will use the term software based radio to cover the technological developments that include SDR. SDR is a step in the ongoing development of software based radio. When fully developed and deployed, SDR is projected to replace many of the traditional methods of implementing both base stations and receivers. This technology will offer a wide range of advantages over current systems including

[1] *Inquiry Regarding Software Defined Radios*, ET Docket No. 00-47, FCC 00-103, (rel. Mar. 21, 2000) ("*NOI*")

adaptability, reconfigurability, and multi-functionality encompassing modes of operation, radio frequency bands, air interfaces, and waveforms.

No Rule Changes Are Needed at This Time, But the Commission Should Encourage the Industry to Develop Standards

BellSouth believes that software based radio will play a key role in resolving non-uniform standards and interoperability issues resulting from the plethora of wireless systems and standards not only in commercial wireless applications, but also government and defense applications as well. BellSouth expects this technology to provide solutions that bridge multiple technologies over the next several years.

BellSouth further anticipates that software based radio technology will reshape the wireless industry in the next few years. It is a viable technology and is already being deployed in the early stages of current commercial wireless cellular and personal communications system (PCS) base stations. A number of chip and software vendors are currently developing products to support initial implementation of software based radio in terminals within the next two years.

Today and in the near term, SDR is merely an implementation technique that uses new and developing software in the same type of equipment that is being built currently. These combinations of software and hardware will operate within the same parameters as present equipment. Therefore, BellSouth believes that there is no need for changes in the Commission's authorization rules or policies at this time. The Commission should continue to focus its efforts on type acceptance procedures, especially those that prevent spurious transmissions, throughout all stages of software based radio development and deployment.

As software based radio technology matures, the industry and the marketplace will drive the development of standards. BellSouth does not believe that it is necessary for the Commission to be actively involved in the standards setting process nor are any rule changes necessary in the near future to encourage implementation of this technology. However, the Commission needs to stay aware of developments in this area so that if regulatory changes are necessary, it has the understanding needed to take the necessary action. BellSouth encourages the Commission to continue participation in industry forums and to encourage a dialog among all sectors within the industry including manufactures, suppliers, carriers and users.

In addition, the Commission should support worldwide industry efforts to make the advances promised by this technology available not only in the United States, but in all wireless communications markets. The Commission can do this by encouraging foreign regulators to adopt flexible policies and to discourage restrictions on the efficient deployment of software based radio. The Commission can play an important role in providing guidance to foreign regulators and supporting the standards developed by the applicable international groups.

Development of Software Based Radio Applications Should be Allowed to Progress Differently Among Three Major Markets

Software based radio is applicable to virtually every marketplace for wireless. It is generally considered that there are three major application universes: commercial wireless *(e.g.*, cellular, PCS, and land mobile), civil government *(e.g.*, public safety, local, state and federal communications), and military. Each of these major markets has a differing set of criteria *(e.g.*, cost, weight, size, performance, and features) that must be taken into account when considering the evolution, application, and deployment of

software based radio. However, there is significant overlap in the applicability of software based radio across these market segments which acts as a strong driver for the development and adoption of software based radio.

BellSouth, like other commercial wireless providers, evaluates software based radio as it relates to cellular, PCS and related services. While cognizant of the other markets, and aware that functionality across all markets would probably lead to increased synergies and cost savings, BellSouth must focus on a cost-based business model. This is necessarily different from the government and defense markets with their distinctive priorities, user groups, and abilities to mandate changes. For example, it is unlikely that a solution that requires the rapid change out of all, or even a large proportion, of base stations and/or handsets is realistic in the commercial market; however, it might be feasible for the military or various public safety organizations. As a result, this technology is likely to be deployed at a different pace in each of these markets based on a varying set of needs, economic realities and capabilities. Therefore, the Commission should not assume that an application or development that is successfully deployed in one market will work in other markets where it might not make sense.

Software Based Radio Will Increase Spectrum Efficiency, But It Will Take Years to Achieve This Effect

It is important to carefully define terminology when discussing the potential impact of software based radio technology on spectrum issues. Spectral efficiency may be viewed as a bits per second per hertz issue. Spectral efficiency is but one component of spectrum utilization which is a measure of how fully the spectrum is being used. BellSouth believes that software based radio technology may have a positive impact on spectral efficiency because, for example, it might facilitate the development, use, and

retrofit of more spectrally efficient modulations. However, particularly in commercial wireless applications (cellular, PCS, and third generation systems), modulation and similar parameters have already been defined and adopted in international standards setting bodies and major changes are viewed as unlikely over the next several years. Therefore, it is anticipated that any impact of software based radio on spectrum efficiency will be several years in the future, at a minimum.

Furthermore, BellSouth does not believe that software based radio can be expected to lead to major enhancements in adaptive spectrum sharing, flexible spectrum management, or interruptible spectrum usage for ten years or more. Adaptive spectrum management goals can not be achieved until adaptive intelligent software radio techniques are widely available in both handsets and base stations. In addition, achievement of these spectrum goals requires sophisticated interaction between the network infrastructure and the handset and requires input data from a number of different sources.

One major obstacle to certain arrangements of sharing and/or flexible spectrum management is that to take full advantage of these potential advanced capabilities may require that all technologies intending to occupy certain spectrum were designed with spectrum sharing and/or flexible usage in mind at the onset. This is, of course, an even greater impediment to non-software based radio implementations having any impact on spectrum usage and management over any timeframe.

Despite the flexibility offered by software based radio it may be difficult, if not impracticable, to retrofit deployed systems to accommodate dynamic spectrum sharing or

real-time flexible spectrum management concepts[2]. This is due to the fact that many radio systems in standardization today and most of those deployed were designed and optimized to operate in dedicated unshared spectrum. Therefore, the Commission cannot assume that software based radio will have much, if any, impact on spectrum availability/shortage issues for at least ten years, and probably longer.

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[2] These concepts are referred to in Paragraphs 15 and 16 of the *NOI* as "short-term sharing" and "interruptible spectrum".

CONCLUSION

For the reasons set forth above, no changes in Commission rules appear necessary at this time. Rather the Commission should exercise its leadership role to ensure that the deployment of this technology is not restricted in other countries. The pace of deployment of this technology is likely to vary between markets based on differing needs, users, and abilities to mandate and finance change. Therefore, the Commission should not assume that what is appropriate in one market can be realistically implemented elsewhere. Finally, in spite of the promise of this technology to provide for an efficient solution for interoperability within spectrum bands and services, software based radio will not have an impact on the need for additional spectrum for at least ten years, and probably longer.

Respectfully Submitted,

BELLSOUTH CORPORATION

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June 14, 2000

CERTIFICATE OF SERVICE

I hereby certify that I have this 14th day of June, 2000 served the following with a copy of ***COMMENTS OF BELLSOUTH ON SOFTWARE DEFINED RADIOS*** BY electronic filing and by depositing the same in the United States mail, postage prepaid.

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June 14, 2000

ATTACHMENT A

General Comments on Software Based Radio Technology

1 Introduction

The FCC is asking fundamental questions in several general areas regarding software based radio:

1. State-of-the-art of software based radio technology
2. The capability of software based radio to resolve non-uniform standards and interoperability issues
3. Spectrum issues such as the applicability of software based radio to enhance spectrum efficiency, spectrum utilization and dynamic spectrum sharing and the need to change spectrum management processes
4. The need to change technical regulatory processes as a result of software based radio technology
5. Validation, verification and auditing issues associated with software based radio

Software based radio, also known as "software defined radio" or just "software radio," is a technological innovation that is coming of age for wireless communications of many types. This technique for construction of wireless devices is expected to replace many of the traditional methods of implementing transmitters and receivers. It will offer a wide range of advantages including adaptability, reconfigurability, and multifunctionality that encompasses modes of operation, radio frequency bands, air interfaces, and waveforms.

The terms Software Defined Radio ("SDR"), Software Radio ("SR") and Adaptive Intelligent-Software Radio ("AI-SR"), as defined in Appendix A, will be utilized in this discussion to denote specific implementation stages of software based radio. BellSouth prefers software based radio as a generic term for this technology in responding to this *NOI*. Usage of the term software based radio will mean that the information is generally applicable across all manifestations of the technology. Software based radio includes both software signal processing of the radio signal and software control of the radio parameters, as defined in Appendix A and illustrated in Appendix B.

The term software based radio is applicable to many differing markets for wireless products and services. A common distinction that has been made is to consider three major application universes:

- commercial wireless *(e.g.*, cellular, PCS, and land mobile),
- civil government *(e.g.*, public safety, local, state and federal communications)
- military.

Each of these major markets has a differing set of criteria *(e.g.* cost, weight, size, performance, features, etc.) that directly impacts the application and definition of software based radio as applied to each of these domains. This must be taken into account when understanding the evolution and influence of software based radio. There is however, significant overlap in the applicability of software based radio across these market domains and this is a strong driver for the development, and adoption of software based radio. This discussion will focus on software based radio as principally applied to the commercial wireless domain.

Increasingly, reconfigurability, flexibility, multi-band, and multi-mode characteristics are being required in all types of radio based communications systems including commercial wireless services, military communications and civil government services. Many of these systems are being evolved into their next generation counterparts. As a result, these systems face the problems associated with a deployed embedded base and the need to preserve continuity across both the old and new systems, often over a transition interval that may span many years.

There is an increased expectation of usability by those who deploy systems and by the end users of such systems. Manufacturers of systems face related concerns in providing product into these market places.

Consequently, broad interoperability among diverse systems using many frequency bands, often on a global basis, forms a baseline requirement now and into the future. In the longer term, the ability to evolve an embedded base of deployed wireless systems, both infrastructure and terminal devices, to accommodate new capabilities on a dynamic basis will become an additional key design factor. Solutions to dynamic reconfigurability includes both a versatile hardware and software environment and the ability to provide updated, enhanced or replacement capabilities via a download mechanism.

2 Software Based Radio Technology - Basic Concepts

Sometimes the words “software defined radio”, “software radio” and “software based” radio are used interchangeably. Because this is a new technology, however, it is very

important to understand its capabilities and limitations. As with any new technology, the terminology used by the various proponents of that technology are not necessarily always consistent. The following overview is provided to establish a common foundation of understanding for the remainder of this discussion and BellSouth's answers to the Commission's specific questions.

In this document we use software based radio as the overarching concept to cover both software-based processing of the radio signal and software-based control of the radio system. Software defined radio and software radio generally apply to the processing of the radio signal while cognitive radio and adaptive radio are terms used to describe intelligent radio concepts in which the radio adapts to its operating environment. There is general acceptance of the notion that the software defined radio evolves to the software radio as the digitization moves to, or very close to, the antenna. Definitions of the following terms may be found in Appendix A:

- Software based radio
- Software defined radio
- Software radio
- Adaptive intelligent software radio
- Digital radio
- Multi-band
- Multi-mode

In considering the architecture of the radio device, whether terminal or base station, it can be divided into two major functional areas:

- Radio Front End - the radio frequency aspects, for both receive and transmit functions
- Radio Back End – the signal processing functionality

Presently, this subdivision leads to an artificial assigning of hardware as the dominant element of the front end and hardware coupled with software as the dominant element of the back end. These assignments to hardware and software will certainly change over time, with software becoming the dominant driver and the hardware moving to a supporting role, particularly as core technologies advance. In the terminology used in this document, the software defined radio evolves to a software radio as the digitization moves closer to the antenna, *i.e.*, as the digitization ideally occurs at, or very near to the antenna.

It is important to separate the notions of software defined radio or software radio from what some have defined as cognitive radio, smart radio, or adaptive radio. In this paper, we use the term adaptive intelligent-software radio (AI-SR) to incorporate all of the concepts of adaptive radio.

The basic concept underlying the adaptive-intelligent radio terminology is the ability of the radio to adapt to its environment by automatically adapting (*i.e.*, without human intervention) its operational mode to achieve enhanced performance and efficiency. This requires the use of artificial intelligence, significant computational power to process

adaptive algorithms in real-time, and real-time data from a variety of sources including the mobile network infrastructure, RF bands available, air-interface protocols, user needs, applications, minimum performance requirements (which might be subscriber dependent as well as application dependent) the propagation environment, and the capabilities of the software based radio platform.

Thus, the adaptive intelligent software radio is an extension of the SDR and SR concepts as defined above. As a simple example of this extension , the radio might adapt in real time to the propagation environment by using a more robust waveform as the propagation environment rapidly deteriorates. Although at first glance this might appear relatively easy to implement, in reality it is very complex because of the need to interact with the mobile network infrastructure and the need for the radio to process all of the inputs described above.

In summary, there are basically two distinctly different aspects of software functionalities that may be incorporated into a radio:

1. Software processing of the information signal.
2. Software control that provides intelligent adaptation of the radio parameters to achieve higher performance *(e.g.*, lower bit error ratios for data transmission) and/or greater spectral efficiency *(e.g.*, higher bits per second per Hz) as the radio adapts automatically to its environment.

These two distinctions of software functionalities in current and future radio technology are directly related to two of the fundamental questions in the *Notice of Inquiry*:

1. The capability of software based radio technology to address interoperability issues resulting from the plethora of wireless communications systems.
2. The ability of software based radio technology to achieve greater spectral efficiency and spectrum utilization (including dynamic spectrum sharing and interruptible spectrum).

BellSouth is enthusiastic about the ability of software based radio to address critical interoperability issues for a wide variety of applications and to provide multi-mode, multi-band capabilities for commercial wireless systems in the near term. However, BellSouth does not believe that software based radio using adaptive intelligent radio concepts can solve spectrum efficiency and spectrum management issues for ten years or more, particularly for non-military applications. The adaptive intelligent aspects of software radio which could ultimately lead to adaptive, dynamic spectrum sharing can be viewed as an even longer-term evolution of radio technology.

Figure 1 shows the evolution of technology from software defined radio to software radio to adaptive intelligent software radio. The triggering mechanisms for the evolution of SDR to SR are advances in signal processing technology including analog/digital ("A/D") and digital/analog ("D/A") converters, faster signal processors and memory chips.

Advances in these core technologies are necessary to move the digitization of the radio signal from the base band to the intermediate frequency (IF) stage to the RF stage (near to the antenna in the ideal SR radio). Advances in intelligent network algorithms are necessary to trigger the further evolution of software radio to the adaptive intelligent software radio capable of enhanced spectral efficiency through adaptive spectrum sharing and spectrum management.

Note that the evolution for commercial wireless handsets is on a different time scale than that of commercial wireless base stations -- the latter will evolve more quickly than the former. The full benefits of the technology requires fully deployed software based handsets and software based base stations in order to begin to achieve alternative approaches to spectrum management including dynamic spectrum sharing. In addition to this full deployment, complex adaptive algorithms must be developed as described in Appendix B.

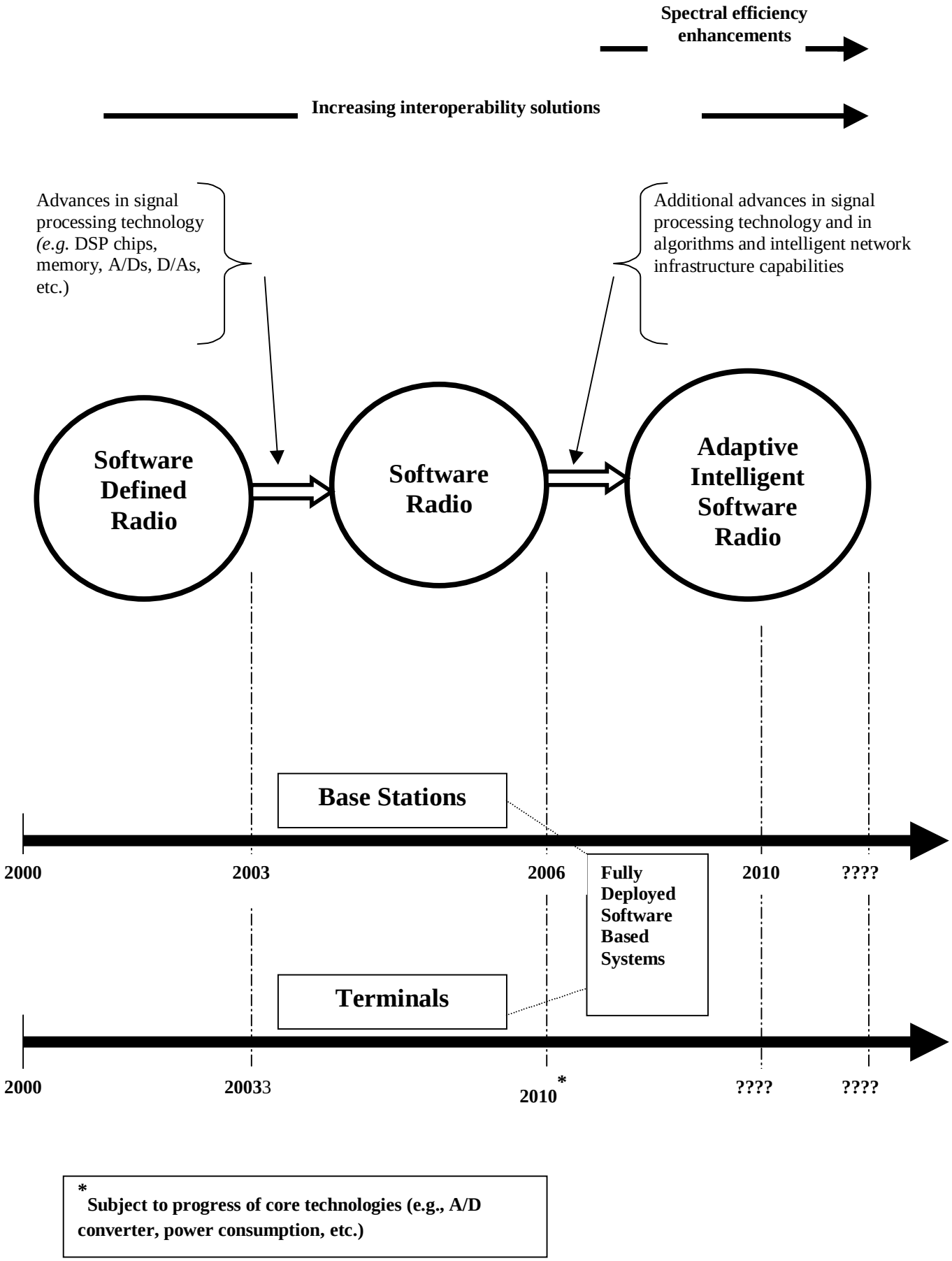


Figure 1 . Time phasing of the evolution of SDR into SR and AI-SR

Att

3 General Comments on Non-Uniform Standards and Interoperability Issues

The commercial wireless industry, particularly the service providers and operators such as BellSouth, as well as end users of commercial wireless services have great concern about the multiplicity of standards for these systems and services. BellSouth has demonstrated its concern about these interoperability issues and its confidence in software based radio technology to address these issues by taking leadership roles in the Software Defined Radio Forum and funding the development of software based radio handsets.

Initially, it can be expected that the universe of radios employing software based radio technology will be a limited set of applications, *i.e.*, only within the commercial wireless applications domain. Ultimately this universe of cross-over applications might include defense and Civil Government applications (*e.g.*, public safety) in a single design for handsets and for base stations. In other words, the ideal handset might have the flexibility to adapt to commercial wireless, military or public safety applications and requirements through simple software changes. This could be the ultimate solution to interoperability issues.

It can be expected that per unit prices would drop because of the volumes that would be produced. However, even absent a market driver for cross over application interoperability, *e.g.* public safety/commercial wireless, the benefits of a software based radio continue to be present at the design and manufacturing level. These benefits of

software based radio, including solutions that bridge multiple technologies, are expected to start happening within the next several years.

4 General Comments on Applicability of Software Based Radio to Spectrum Issues

Theoretically, software based radio could help solve spectrum utilization issues through adaptive spectrum management techniques, *i.e.*, spectrum on demand. This is discussed in Appendix B which includes a figure that depicts the evolution to AI-SR.

However, it is BellSouth's view that a significant impact of software based radio technology on spectrum sharing, flexible spectrum management, and interruptible spectrum will not occur for ten years or more in the commercial wireless arena. The reason for this is that these spectrum benefits of software based radio technology require not only an adaptive radio technology, but also complex artificial intelligence (AI) technologies.

From a commercial wireless perspective these AI technologies must be present in both the base station and the handset. Furthermore these technologies must be fully deployed (*i.e.*, achieve critical mass in the marketplace) to achieve the desired efficiencies. Also, the adaptive capabilities must be designed into the system at the very start, *i.e.*, it can not be added on to existing systems. Indeed, it is likely that partial implementations of these concepts within a given system or systems may not achieve any benefit and that it may require an almost total solution to be deployed before any substantive benefit accrues. Because the technical specifications of IMT-2000 systems have only recently been

standardized, it is unlikely that new adaptive capabilities will be standardized and deployed in the near future.

5 General Comments on Technical Regulatory Issues Associated With Software Based Radio

The initial phases encompassing SDR can be viewed as simply a new platform for implementing typical radio signal processing functions such as filtering, modulation, etc. These functions which historically were performed on analog signals can now be performed digitally - either by digital hardware using application specific integrated circuits (ASICs) or in software using programmable digital signal processors or other high-speed computing devices. Using this view, the initial phases of SDR will require no new regulatory policies or procedures because of the limited additional flexibility afforded by the early stages of SDR. Several years in the future, as additional flexibility is added, particularly flexibility achieved through software downloads to the SDR devices, it may be necessary for the Commission to adopt flexible new standards and rules to encourage the widespread commercial deployment of this technology.

Adaptive intelligent software radio, as previously described and as illustrated in Appendix B, is the “ideal” case. For the foreseeable future technology limits the flexibility and scope in achieving the ideal because it requires not only fully deployed AI-SR technology in both the handset and base station, but also requires significant new adaptive algorithms in the network infrastructure (see Appendix B).

Software based radios typically could select from multiple frequency bands, multiple modulation techniques (each of which has a different spectral mask), and different transmitted power levels which might be associated with different modes of operation. Initial applications of SDR technology through 2001, predominantly to consolidate product platforms, are expected to require little or no change to traditional equipment authorization rules used by the FCC and other regulatory organizations.

The complexity associated with software based radio begins to increase when software download capabilities (either over the air or via some other mechanism) are incorporated into wireless equipment and services. Initial exploratory activities have in fact already begun via meetings and joint workshops between regulators, including Commission staff, and the SDR Forum. Therefore, it is important for the Commission to keep abreast of these developments.

It will be extremely important for future regulatory efforts to address global issues. One of the driving factors for the harmonization of CMRS standards is the need to accommodate global circulation of mobile terminals[1]. The Trans-Atlantic Business Dialog (TABD) is expected to promote a policy that urges both the European Union (EU) and the United States Governments to remove all formal and de facto regulatory barriers

[1] The term "global circulation" used in this context means roaming across national boundaries. Experts in the wireless field sometimes use the term "global roaming" to mean roaming across different types of networks. From a technical point of view, the latter is the most significant aspect of roaming. From a regulatory point of view, global circulation is the more relevant issue.

that may prevent individuals from carrying their personal mobile IMT-2000 terminals into the EU and US territories respectively[2].

Clearly, meeting type-approval regulations is a critical and necessary aspect of introducing new wireless devices and services, from the perspective of both the regulators and network operators. It is not only the regulators that have concern about spectral emissions. Operators of wireless systems have fundamental business reasons to ensure correct and proper operation of flexible wireless devices in all situations. For example, improper transmitter operation is likely to have a negative impact on the quality-of-service (QoS) that can be provided to the end user.

6 General Comments on Validation, Verification, and Auditing Issues Associated With Software Based Radio

New validation, verification, and auditing issues associated with software based radio will be needed in the future because of the flexibility associated with software based radio. This flexibility includes frequency bands, power levels, modulation techniques, and bandwidths. Essentially all radio functions ultimately could be affected by software defined radio and software controlled radio. Obviously, operators have a strong business interest in ensuring that the flexibility inherent in software based radio devices is not misused in either a fraudulent manner or unintentionally in a manner that reduces performance to the end user or compromises system integrity. As an example, if software control on power control were not properly implemented, RF power could fluctuate and cause poor performance and user dissatisfaction. Therefore, BellSouth is strongly

[2] Output from EETIS Meeting (October 1, 1999) that is provided as input to the TABD Berlin 1999 Meeting.

motivated to work with the Commission to keep it informed as these type acceptance, validation, verification, and auditing issues in step with the increase of software based radio capabilities.

ATTACHMENT B

BellSouth Responses to Specific Questions

1 Overview of Specific Responses

In this section, BellSouth provides responses to explicit questions stated in the *Notice of Inquiry*. BellSouth responds to paragraphs 9, 11, 17, 19, and 21. BellSouth responses are sequentially numbered for each question within these paragraphs.

2 Response to Questions on State-of-the-Art of Software Based Radio Technology (*NOI* Paragraph 9 Questions)

- **Question 9-1: What features in a radio are apt to be controlled by software? For example, could the operating frequency, output power, and modulation format be software controlled?**

In today's commercial wireless radios, especially those using digital signal processing, a large number of parameters are a combination of hardware and software *(e.g.*, firmware). The issue is not what you control, but the accessibility of the control. Either purposeful design or an unintended embedded control system that becomes much more open and accessible leads to questions on flexible control and to associated questions on validation, validation, and auditing (*i.e.*, the questions raised in Paragraph 21 of the *NOI*).

Figures 1a and 1b in Appendix B distinguish two distinct aspects of software based radio:

1. software processing of the information signal between the antenna and the user's input/output device
2. software control of the radio's parameters

Certainly, the operating frequency, output power and modulation format can be under software control. The difficult issue is whether this software control is automatically adaptive control (adaptive intelligent software radio) or requires human intervention. Moreover, in regard to the software processing of the information signal, it is not likely that the RF section of the radio will be truly a software radio for some time, *i.e.*, digitization near the antenna will not occur in the near future for commercial wireless. Nevertheless, it is possible to have separate RF hardware modules that can be switched in or out of the radio by human control, rather than automatic control, for the near future.

- **Question 9-2: What are the specific limitations of current software defined radio technology? What are the cost implications?**

The limitations of software defined radio are analog/digital ("A/D") converters, DSP processing capabilities, memory and ultimately adaptive processing algorithms that interact with intelligence in the mobile network infrastructure.

Technology drivers for software defined radio applications to 2G, 3G and beyond commercial wireless systems, as well as to civil and military systems, include hardware such as:

- High-speed, low-power digital signal processing devices
- High-speed, high resolution A/D and digital analog ("D/A") converters
- High dynamic range RF tuners and associated filters and amplifiers
- Highly linear, broadband diplexers
- Development tools
- Advanced signal processing algorithms

- Fast, high-density, low-power memory devices

The above hardware components must be available at a reasonable cost and enable efficient implementations in terms of power and size for software based radio concepts to be applied to commercial wireless infrastructure equipment and user terminals.

In addition to the many hardware elements discussed above, the engineering of advanced, modular, and robust software architectures for the definition, interfacing, and control of RF, baseband, application, service, and network functions is also a critical area of software based radio development.

Although the *NOI* is directed specifically toward software based radio technology, it is important to keep in mind that rapid advances are being made in both analog and digital hardware devices as well. In other words, the processing of the information signal could be done in analog devices, digital hardware, or via software code that is executed on a programmable digital processor (most likely done using some combination of the preceding). It is likely the RF front end of the radio will be analog for some time to come. Nevertheless, some of the desired characteristics of a radio which are associated only with software defined radio will really be achieved initially by advances in the present methods of implementation. Multi-band radio, for example, may initially be achieved by advances in ”conventional” design rather than solely in software based radio implementations. These analog multi-band radios may be under software control, so in that sense they belong to the family of software based radios, especially if the baseband processing stages of the radio are flexibly implemented.

Software based radio is expected to lower costs to consumers, service providers/operators and manufacturers. Manufacturers benefit because of increased volume and economies of scale. A single software based radio terminal design or a single base station design will be capable of operating in many different modes. Service providers/operators have a cost benefit because a single platform could be used for a multiple standard base station. This would make upgrades or changes in air interfaces feasible through software downloads instead of hardware upgrades or switching out the entire base station. Finally, in addition to efficiency and convenience, there will be a cost benefit to users because a single terminal could be used for multiple operational modes.

- **Question 9-3: What capabilities could software defined radios have that are not found in current radio technology?**

Software based radios could have multi-band, multi-mode, and multi-function capabilities that are not present in current radios. It is important to note that these aspects could be achieved through hardware, software, firmware or some combination of the three, although the result is likely to be a bulky, expensive and perhaps power-hungry device. The importance of software based radio concept is that it provides flexibility to the manufacturer, to the network operator or service provider in the case of commercial wireless, and to the end user. This flexibility provides increased operational modes that can not be economically attained without the use of software based radio technology. Capabilities of software based radio are illustrated in Table 1.

Table 1 Multi-Capability Definition

- **Multi-Function** *(to support customer wants and needs)*
  - variety of service features
    - fixed & mobile convergence; voice, data - (high, medium, & low speed) messaging, paging, locating, image, caller ID, privacy, voice recognition, multimedia....
- **Multi-Mode** *(to support evolution from today's systems to tomorrow's deployments)*
  - plethora of "environments"
    - analog, digital, fixed, mobile, terrestrial, satellite, embedded....
- **Multi-Band** *(to support evolution from today's systems to tomorrow's deployments)*
  - numerous frequency bands
    - cellular, PCS, paging, data, SMR, satellite, cordless telephone, international....

- **Question 9-4: When could software defined radios be deployed commercially, and for what services or purposes?**

In answering this question, it is important to carefully distinguish between stages of software defined radio, software radio, and adaptive-intelligent software radio as described in our General Comments in Attachment A and as defined in Appendix B and illustrated in Appendix B.

SDR technology is expected to play an increasing role in the wireless industry in the next few years. SDR is a viable technology that is already being deployed in the early stages of current cellular and PCS base stations. At present, it does not appear that SDR is used on handsets. However, a number of chip and software vendors are developing their products to support SDR in terminals within the next two years.

Timelines for the Application of software based radio to Commercial Wireless Systems

Expected timelines for software based radio adoption in wireless infrastructure equipment, user terminals, and other products are presented in Figure 2.

Infrastructure:

<2001	Initial limited use by commercial cellular infrastructure manufacturers and military/ aerospace equipment manufacturers
2001…	Increased commercial, civil, and military use, driven by the development and initial deployment of third generation commercial wireless systems and the need for multi-service capabilities in civil and military markets
2005…	Widespread adoption by most manufacturers as core platform

User Terminals:

<2001	Many R&D efforts worldwide, little commercial usage
2001…	Initial usage to meet growing demand for multimode, multiband product platforms for 1G and 2G commercial wireless market, as well as civil and military markets
2003…	Increased usage to add 3G commercial wireless capabilities
2005…	Widespread adoption and movement to SDR as baseline design

Other Products:

<2001	Fielded applications in various radio/ wireless products
2001…	Increased usage in wireless and non-wireless products as SDR technology matures
2005…	Potential for widespread utilization in products receiving/transmitting in the 100MHz range

Figure 2. Expected software based radio evolution timelines

Today, first-generation SDR is a viable technology that is already being employed in a limited manner in cellular and PCS base station products, as well as in military and aerospace equipment. However, despite extensive research efforts worldwide, SDR is not yet widely utilized in commercial user terminal products. Also, the full advantage of the flexibility and in situ adaptability that software based radio could ultimately provide in the future is not currently available. Today, SDR is essentially used as an enabling or substitute technology for the manufacturer to consolidate product platforms.

Evolution of Software Based Radio Base Stations

Base station manufacturers have adopted SDR technology initially to reduce the number of product platforms that must be developed in order to support multiple air interfaces, and to enable product architectures that can be systematically scaled to incorporate new and evolving capabilities. However, the need for base stations that can offer network operators a means to transition from 1G and 2G technologies (AMPS, TDMA, CDMA, GSM, etc) to 3G technologies and provide seamlessness and simultaneous RF coverage between all technology generations will drive SDR and SR to be a dominant base station implementation. These next-generation base stations will use wideband digitization and software-based signal processing to support multiple modes in the same system at the same time.

Evolution of Software Based Radio Based User Terminals

It is anticipated that SDR will grow rapidly in importance in the next few years for the development and deployment of commercial, civil, and military wireless user terminals. The initial market thrust will be to take advantage of the technology to deliver multi-mode and multi-band terminals that have richer capabilities than those available today. This market will also meet such requirements as cost, size, weight, battery life, and the introduction of advanced voice, data, multi-media services. The first step may be substitution of SDR technologies to replace "Velcro" approaches to building terminals with multiple application-specific integrated circuits. Subsequent steps will utilize SDR to provide flexible and customizable features and services on common platforms.

Evolution of Software Based Radio Commercial Wireless Systems

As wireless networks evolve further and standards are introduced for software download, software based radio will be exploited to offer capabilities such as the following:

- user terminal reconfiguration for over-the-air provisioning and upgrading of core capabilities, user features, applications, and services;
- downloading of “bug” fixes;
- full download of new air interfaces, etc;
- support of smart antennas and active interference control;
- improved user location capabilities and new location-based services**.**

However, as pointed out in our answers to the questions raised in paragraph 17 of the *Notice of Inquiry*, just because software based radio equipment will be in use does not mean that it will alleviate spectrum availability problems at that time.

- **Question 9-5: What work is being done on software defined radios internationally, and are there any steps the Commission should take to encourage this work?**

There is a considerable amount of research on software based radio being conducted in all regions of the world. In Europe, the European Commission is funding research on what they term “reconfigurable radio” under the Advanced Communications Technologies and Services ("ACTS") program. Likewise in Asia, software defined radio is the subject of many research papers generated by researchers in both industry and academia. In the United States, the Department of Defense has sponsored numerous software defined radio programs during the last decade.

BellSouth understands that many of its existing suppliers have programs in place to utilize software based radio in their products. Furthermore, a number of new companies dedicated to developing software based radio core and enabling technologies as well as radio products have emerged. Many of the international organizations conducting software based radio developmental programs are members of the Software Defined Radio Forum.

In addition to interaction with U.S. based proponents of software based radio, the SDR Forum has established communication channels with the European Commission ACTS Program which sponsors research in software defined radio and reconfigurable radio. Through its membership, the SDR Forum also has strong contacts with the research community in Asia. To ensure international participation, the SDR Forum schedules meetings in many different locations throughout the world.

The Commission can help promote this international work by continued active participation in the SDR Forum and by discussion of software based radio regulatory issues during bilateral discussions with regulators from other countries. In particular, it is important for the Commission to encourage foreign regulators to be flexible in order to ensure that widespread deployment of this technology is not hindered by regulatory roadblocks.

3 Response to Questions on Non-Uniform Standards and Interoperability Issues (*NOI* Paragraph 11 Questions)

- **Question 11-2: To what extent can software defined radios improve interoperability between equipment and services using differing transmission standards?**

While software based radio technology can make differing standards appear to be transparent because of flexibility, there is perhaps a practical limit on the number of standards and the breadth of dissimilarity of key radio parameters (*e.g.*, radio frequency, bandwidth, modulation, etc.) in a practical product. It may be difficult to cover multiple frequency bands that are widely separated in a practical software based radio. In other words, in the early stages of SDR technology development, one cannot expect the universe of radio standards, frequency bands, modulations and application's to be made compatible in a single device. As the software based radio technology evolves from SDR to SR, we will be able to apply it over an increasingly large universe of differing standards, frequency bands and modulations.

- **Question 11-3: To what extent would software defined radios move toward uniformity in standards within or across bands?**

As noted in the response to the previous question, software based radio technology will have the near-term effect of improving interoperability for different operational modes. In the longer term, one might expect a reduction in the number of different operational modes as users naturally gravitate to those modes that are most efficient and which provide the highest performance.

- **Question 11-4: To what extent can software defined radios be used to facilitate transitions from one technical standard to another, such as the transition mandated by the land mobile "refarming" proceeding?**[1]

This question is closely related to the previous question in that software based radio technology will initially provide multi-band, multi-mode capabilities and then will provide a mechanism for gravitation to fewer standards. Software based radio technology is applicable to band-splitting issues such as the land mobile radio "refarming". The technology provides a mechanism for operation in legacy modes while moving to new operational communication modes for the future.

- **Question 11-5: What particular means could be employed by software defined radios to facilitate interoperability?**

Software based radio can facilitate interoperability by providing multi-band, multi-mode capabilities. Through software upgrades that are consistent with the overall capabilities of the underlying hardware platform, software based radio provides flexibility for addressing interoperability problems. For the commercial wireless applications, there are a limited number of modulations, bandwidths, and frequency bands needed to accommodate current and future commercial wireless applications (cellular, PCS, and IMT-2000).

[1] In the land mobile "refarming" proceeding, the Commission mandated that the channel spacing in the private land mobile bands be reduced from 25 kHz to 12.5 kHz, then to 6.25 kHz. *See Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them and Examination of Exclusivity and Frequency Assignment Policies of the Private Land Mobile Radio Services*, PR Docket 92-235, *Report and Order and Further Notice of Proposed Rule Making*, 10 FCC Rcd 10076 (1995).

Exact methods necessary to ensure fully supported interoperability within a particular market domain or across market domains are a subject for continued study and development. It may not be sufficient to just have a flexible platform, other aspects of intersystem operation may be required to also evolve to support the flexibility offered by software based radios. For example, there may be a need to ensure that a customer's service profile can be appropriately accessed across the diverse systems. In addition, consideration may be required for the interaction of "back office" systems such as billing and call accounting.

4 Response to Questions on the Applicability of Software Based Radio to Spectrum Issues (*NOI* Paragraph 17 Questions)

In answering the questions posed in *NOI* Paragraph 17, it is important that all parties have a common understanding of spectrum usage and spectral efficiency. To this end and for the purposes of this response BellSouth submits the following definitions:

Spectral efficiency - this is a measure of a radio's capacity, *e.g.*, the bits/second per Hz capability.

Spectrum usage - this is a measure of the level of utilization, *i.e.*, information transmission capability, of a given frequency band.

Spectral efficiency may be viewed as one of many components of spectrum usage.

BellSouth is optimistic that software based radio technology is a platform that may permit reasonable implementation of new modulations which will improve the spectral efficiency of the radio. Since spectral efficiency is one component of spectrum usage, SDR technology could have an positive impact on spectrum usage as well. However,

BellSouth is not optimistic that the concept of leased airtime, spectrum sharing, and interruptible spectrum, as the terms are used in Paragraphs 15 and 16, will be viable for many years to come.

In Paragraph 15, the Commission introduces the notion of "short term spectrum sharing" and in Paragraph 16 the term "interruptible spectrum" is used. BellSouth understands these terms to mean real-time, dynamic sharing of spectrum between different licensed users in a given band. While this may be a desirable long term goal, BellSouth believes that this is not practically feasible for many years for the following reasons:

1. Short term spectrum sharing for commercial wireless applications would require fully deployed adaptive, intelligent software radios (as defined and illustrated in Appendices A and B respectively).
2. Short term spectrum sharing would require adaptive algorithms that are currently non-existent. Research in adaptive intelligent radios, which some call cognitive radio, is only in its embryonic stage.
3. The wireless industry has only recently completed the development of third generation (3G) wireless standards. Even if the wireless industry accepts the concept of adaptive intelligent software radios, it would take years for this concept to be implemented in commercial wireless standards that go beyond IMT-2000. It would be many years after such standards are developed before the technology would be sufficiently deployed in commercial wireless systems for short-term spectrum sharing to be feasible.

In paragraph 16, the Commission introduces the concept of using a "beacon system". The commercial wireless industry has already decided against the use of a separate control channel or beacon capability. This was evidenced by the positions taken by many administrations and other parties in addressing WRC-2000 agenda item 1.6.2 on global control channels. Even if the deployment of a beacon system were agreed to today, it would take many years for development and full deployment of base stations and handsets having the functionalities described in the *NOI* Paragraph 16. However, BellSouth believes that the issue of a global control channel may need to be revisited in the future as a facilitating mechanism for software based radio.

- **Question 17-1: To what extent could software defined radios improve the efficiency of spectrum usage?**

In the long term (post-2010), it may be feasible that advanced software radio, which we define as adaptive intelligent-software defined radio, could have the capability to sense the environment, change the radio's parameters to adapt to the operational environment, and thereby operate in modes that are the most spectrally efficient for the particular environment. Software based radio might one day be utilized to achieve improved spectral efficiencies, by adapting to network frequency availability and user bandwidth requirements.

However in the commercial wireless world, the level of mobile network intelligence required to enable such performance is not expected to be developed and deployed until systems beyond those already specified for IMT-2000 are introduced, sometime beyond 2010. Fundamental research is still being carried out in this area. Given the intense

efforts currently ongoing to standardize and implement current third generation (3G) and IMT-2000 systems, priority should be given to supporting the regulatory efforts required to introduce concepts in a suitably staged fashion, first in 3G systems and then in systems beyond IMT-2000. Regulatory agencies should focus initially on the issues associated with licensing of systems and type approval of radios that employ SDR to enable 3G services and functionality, rather than diverting resources to exploring SDR as an answer to the spectrum requirement issue associated with the rollout of IMT-2000 systems.

While there will be implementations using SDR technology in the near-term (prior to 2010), SDR should not be viewed as a technology that will reduce the spectrum requirements for IMT-2000. Furthermore, advancements in software based radio technology will not result in increased spectral efficiency in the time frame that is being addressed for IMT-2000 (between now and 2010).

Both the services and technologies today and to be deployed over the next decade or more were developed with a priori expectations on services, spectrum use, spectrum location, etc. In most cases, system design criteria spanning a given geographic area are unique to the services and technology deployed and cannot arbitrarily tolerate foreign systems impinging on its spectrum. For example, coexistence of analog PCS and point-to-point microwave users was found not to be feasible; hence the microwave users needed to be cleared from the band before it was possible to operate PCS systems.

- **Question 17-2: What particular functions related to spectrum usage could a software defined radio perform? Could it locate free spectrum, dynamically allocate bandwidth, and enable better sharing of the spectrum?**

The following is from the CPM 99 Report[2]:

> *"Equipment manufacturers recommend that administrations should not rely on future, possibly costly, technological advancements (e.g. multimode, multiband reconfigurable or fully digitized "software" radios, and adaptive antennas) to provide sufficient spectrum management flexibility and address the difficulties caused by band fragmentation, in order to offer global services without global spectrum. Manufacturers also considered that to do so may lead to unnecessary delay in implementing global services and result in roaming complications for customers, manufacturers and operators."*

Clearly, the manufacturers do not believe that technology is a means to eliminate the need for globally harmonized spectrum. BellSouth supports the position expressed in the CPM report.

- **Question 17-3: How specifically could it carry out these functions?**

BellSouth does not believe that spectrum sharing, as described in the introduction to this Section, will be feasible for many years.

[2] Conference Preparatory Meeting, "CPM Report on Technical, Operational and Regulatory/Procedural Matters to be Considered by the 2000 World Radiocommunication Conference", International Telecommunications Union, Geneva, 1999.

- **Question 17-4: What are the benefits of the spectrum sharing arrangements described above, and what steps might we take to permit the use of software defined radios to enable such sharing arrangements?**

Both the benefits envisioned by the Commission and any others are not practically attainable for many years.

- **Question 17-5: What changes may be appropriate for the way the Commission currently allocates spectrum?**

In the context of Software Based Radio, BellSouth does not believe that there is any requirement at this time for the Commission to make any changes in the way it allocates spectrum.

- **Question 17-6: If changes are warranted, how could we make the transition from the current allocation and licensing model to a new model?**

In the context of Software Based Radio, no changes are required at this time. The issue may need to be re-examined in the future when technology and standards have developed.

5 Response to Questions on Technical Regulatory Issues Associated with software based radio (*NOI* Paragraph 19 Questions)

- **Question 19-1: Should we approve the radio hardware, the software or the combination of them?**

Both hardware and software must be approved as a functional unit. The approval process is potentially further complicated by the fact it is feasible that software and possibly even new hardware modules from third parties may be added to a system that has already been

given approval. The identification of parameters that can be modified in software based radio and the specific steps that the Commission should take are described below.

Identification and characterization of parameters that can be modified in software based radio *equipment:*

The FCC and other national/international regulatory organizations should collaborate to develop policies and procedures that provide guidance as to what information needs to be submitted for each software based radio based wireless device that is submitted for type approval under established equipment authorization rules. While the user will not be allowed to directly change radio parameters, the user (along with the network operator and equipment manufacturer) will be able to change operational mode parameters that will affect radio parameters. The characterization of the software based radio needs to include a mapping from the user-parameter domain to the radio-parameter domain. As an example, if the user changes from a service provider that employs the IMT-2000 CDMA multi-carrier mode instead of a service provider that employs the IMT-2000 CDMA direct-sequence mode, then obviously the filter characteristics will change[3]. Each application for equipment authorization needs to include information that characterizes what radio parameters may be changed and what user actions will cause these changes.

Suggested action/resolution: The FCC and other Government Agencies should keep abreast of the work in the SDR Forum that specify the equipment so they can approve an

[3] These, and other, IMT-2000 air interface modes are described in ITU-R Recommendation M.1457, "Detailed Specifications of the Radio Interfaces of IMT-2000".

authorization procedure for software defined radios when appropriate. As a starting point the following may require consideration by all involved parties:

- Signal Processing Parameters
- Baseband processing parameters and range of permissible values
- Digital IF processing parameters and range of permissible values
- RF processing parameters and range of permissible values
- Input/output processing parameters and range of permissible values
- Radio Control Parameters

Note that the type of information required will change with the passage of time. As digital signal processing algorithms, processing engines, and A/D and D/A technologies become faster and more powerful, software based radio concepts will move closer to the antenna.

- **Question 19-2: Are the currently required measurements in Part 2 of the rules appropriate for software defined radios?**[4]

In the early stages of application of software based radio which merely substitutes technology there should be no impact and no change in the rules is required at this time. However, the FCC and the industry should continue to monitor and assess the situation as software based radio develops.

[4] Part 2 of the rules requires the following measurements on transmitters used in licensed services: RF power, modulation characteristics, occupied bandwidth, spurious emissions at antenna terminals, field strength of spurious emissions and frequency stability. *See* 47 C.F.R. §§ 2.1046 through 2.1055.

- **Question 19-3: How should software defined radio equipment be tested for compliance, including compliance with SAR requirements?[5] What type of approval process and labeling would be appropriate?**

At this stage in the application of software based radio which merely substitutes technology there should be no impact and no changes are required. The FCC and industry should continue to monitor and assess the situation as software based radio develops.

- **Question 19-4: Should we regulate who changes the software and the manner in which it is done? If so, should the Commission maintain records of such modifications?**

Software based radio wireless devices could ultimately incorporate hardware and software components from multiple vendors. Much of the software could be added after initial certification and after purchase by the end user, including software upgrades to fix "bugs", add new service features, or add entirely new modes of operation. The addition of software must be adequately controlled so as to prevent generation and transmission of unauthorized waveforms or power levels.

Suggested action/resolution: Independent authorization of hardware and software might be necessary. However, regulatory actions should not restrict equipment manufacturers from choosing how best to partition hardware and software functionality in their products. Regulatory bodies must devise licensing and type approval methods that

[5] For the purpose of safety, certain transmitters designed to operate within 20 cm of the user are subject to limits on the specific absorption rate (SAR) of radio frequency energy by the body. *See* 47 C.F.R. § 2.1093.

protect other users of radio spectrum yet allow SDR equipment the maximum possible flexibility. Regulators should work with the commercial sector, for example in the SDR Forum, to develop techniques for configuration management and a self-monitoring mode of operation. Proper operation of software based radio commercial wireless systems is of paramount importance to the service providers because abnormal operation and interference would adversely affect system performance and therefore the level of customer satisfaction with the service.

- **Question 19-5: What are the various means that may be used to download new software? We anticipate, for example, that software could be downloaded by methods such as direct connection to a programming device or over the airwaves. To what extent will the software interfaces be standardized?**

Many key advantages of software based radio arise from the ability of equipment manufacturers, network operators, and service providers to differentiate their products and services via software upgrades to infrastructure equipment and mobile terminals. Software upgrades - to add new capabilities and services, fix deficiencies in the software or hardware, or to add entirely new operational modes - could conceivably be executed over the air, over the network, over the Internet, or with a simple procedure at an authorized facility. This flexibility is highly desirable from both a service provider and a user point of view. However, such flexibility requires addressing a number of issues related to security, authentication, and equipment/ network compatibility during, and subsequent to, software downloads and/or upgrades.

Suggested action/resolution:

When the technology and standards have developed to a level beyond the capability of current rules to address, the Commission must devise licensing and type approval methods that protect other users of radio spectrum yet allow SDR equipment the maximum possible flexibility. Regulators should keep track of the work progressing in the private sector to develop techniques for configuration management and a self-monitoring mode of operation. The SDR Forum has already started addressing regulatory issues and is the proper body within which to develop the techniques and detailed specifications for configuration management and self-monitoring requirements to be provided to manufacturers of SDR devices. This will be an evolutionary process, governed by developments in the technologies, standards, and the regulatory framework for SDR. In commercial markets, OEMs should be allowed to assume much of the responsibility for the certification of SDR products.

- **Question 19-6: Should we require anti-tampering or other security features? How would such security features work? Could equipment be designed to prevent it from transmitting in certain designated frequency bands, such as those allocated exclusively for government use, as a safeguard against causing interference?**

Software based radios, like any system that incorporates software, are susceptible to malicious attack. A hacker could possibly generate software that might cause the transmission of unauthorized waveforms. Conceivably viruses of this type could spread

in a wireless network employing software based radio based mobile terminals and base stations.

Legitimate users of the radio spectrum need protection from both willful use and inadvertent use of unauthorized bands. Inadvertent use of unauthorized bands could occur if software based radio based wireless devices are accidentally put into a mode in which they transmit an unauthorized waveform or unauthorized power level. Overall network stability must also be maintained, and the security of individual users' services should not be compromised by the introduction of over-the-air download capabilities.

Suggested action/resolution: One solution may be an access algorithm which will prevent unauthorized users access to the software code embedded in software based radio based systems. The SDR Forum and others are addressing this issue. Therefore, it is not believed that Commission involvement will be required.

Response to Questions on Validation, Verification, and Auditing Issues Associated with SDR (*NOI* Paragraph 21 Questions)

- **Question 21-1: Is there a need for such an approval system, and is it feasible and practical?**

The complexity of the approval issue stems from the fact that the number of modes and combinations of parametric values for software defined radios is potentially very large. Configuration management is the set of technologies and procedures for controlling these combinations. For example, the number of filters that could be implemented, each having different spectral shapes, could be infinite depending upon how the filter is

implemented in software. This leads to the need for a configuration management and possible self-monitoring capability, in order to control the various combinations of hardware configurations and software programs accessible to software based radio equipment.

As software based radio technologies evolve further to allow equipment to adapt to their operating environment - by using the configuration manager to change reconfigurable signal processing blocks and software defined radio processing *(e.g.* IF processing filters) - the self-monitoring module could determine if the resulting transmitted signal is authorized for use in this particular device.

Suggested action/resolution: Regulatory bodies must ensure that licensing and type approval methods protect other users of radio spectrum yet allow software based radio equipment the maximum possible flexibility. Regulators should keep abreast of the efforts of the SDR forum and other industry bodies to develop techniques for configuration management and a self-monitoring mode of operation. Regulatory activities should focus on making sure that appropriate-type acceptance procedures are in place to certify equipment functions and performance, rather than details of product implementation, so as not to constrain commercial innovation of software based radio technologies. The SDR Forum has already started addressing regulatory issues and is the proper body within which to develop the techniques and detailed specifications for configuration management and self-monitoring requirements to be provided to manufacturers of software based radio devices. This will be an evolutionary process,

governed by developments in the technologies, standards, and the regulatory framework for software based radio. In commercial markets, OEMs should be allowed to assume much of the responsibility for the certification of software based radio products.

- **Question 21-5: Is there a need for a method to display information about the software loaded in a transmitter? If so, what method should be used and what information should be displayed?**

Yes, information regarding the installed software and hardware software should be available in the terminal. The information should include information about type approval of each hardware and software module and information about the manufacturers of each of the modules. However, it may be appropriate to consider whether this information is to be available to the end user as a matter of course or is only available by either the user or provider placing the device in an appropriate "maintenance state."

Appendix A

Definitions

Adaptive Intelligent Software Radio ("AI-SR")

An adaptive intelligent software radio is one which is capable of adapting to its operational environment thereby achieving enhanced performance and/or spectral efficiency.

The basic concept underlying this AI-SR terminology is the ability of the radio to adapt to its environment by automatically adapting (*i.e.*, without human intervention) its operational mode to achieve enhanced performance and efficiency. This requires the use of artificial intelligence, significant computational power to process adaptive algorithms in real-time, and real-time data from a variety of sources including the mobile network infrastructure, RF bands available, air-interface protocols, user needs, applications, minimum performance requirements (which might be subscriber dependent as well as application dependent) the propagation environment, and the capabilities of the software defined radio platform. Thus, the adaptive intelligent software defined radio is an extension of the SDR and SR concepts as defined below. As a simple example of this extension , the radio might adapt in real time to the propagation environment by using a more robust waveform as the propagation environment rapidly deteriorates. Although at first glance this might appear relatively easy to implement, in reality it is very complex

because of the need to interact with the mobile network infrastructure and the need for the radio to process all of the inputs described above.

Digital Radio is a radio in which the information is digitized at some point between the antenna and the input/output devices. Digital radio does NOT necessarily mean that the radio is a software-defined radio. A radio may be digital but if the signal processing that takes place after the A/D conversion is performed by special purpose, application-specific integrated circuits (ASICs), it is not a software defined radio.

Multiband is the capability of handsets or base stations to operate in multiple frequency bands of the spectrum.

Multimode refers to the capability of a handset or base station to operate in multiple modes *(e.g.*, multiple air interface standards, multiple modulation techniques or multiple access methods).

Multiband/multimode capabilities may be implemented using a variety of hardware and/or software techniques, including SDR. However, current state-of-the-art SDR technologies cannot yet support economically-viable multiband systems that cover today's widely fragmented and diverse spectrum allocations. Increasing the number of frequency bands requiring consideration in the wireless device exacerbates the design problem and extends the development, implementation and deployment timeline in the marketplace.

Software Radio, Software Defined Radio, and software based radio

There are many understandings of what is considered to be a "**software-based radio"**. A software-based radio can be generically defined as a radio that employs software techniques to process digitized radio signals. The fundamental intent is to shift the traditional hardware-focused, application-specific, approach to radio implementation to that of a "computing platform" using software as the "application" to perform the "radio" signal processing tasks.

Software based radio includes:

1. software signal processing of the information signal as it passes from the antenna to the users input/output device and vice versa, and
2. software control of the radio parameters *(e.g.*, control of the frequency, bandwidth, or modulation parameters)

For clarification and for the purpose of understanding the evolution stages possible in **software based radio** as a function of advances in the underlying core technologies we have chosen two commonly accepted definitions. They are **software defined radio** and **software radio**[1]. As technology progresses, a software-defined radio can move to an almost total software radio where the digitization is at the antenna and all of the processing is performed by software residing in high-speed digital signal processing functionality.

[1] Definitions from material developed by Software Defined Radio Forum. See http://www.sdrforum.org

Definition of the software defined radio

A **software defined radio (SDR)** is defined as a radio in which the receive digitization is performed at some stage downstream from the antenna, typically after wideband filtering, low noise amplification, and down conversion to a lower frequency in subsequent stages, with a reverse process occurring for the transmit digitization. Digital signal processing in flexible and re-configurable functional blocks defines the characteristics of the radio.

Definition of the software radio

As technology progresses, a software defined radio can move to an almost total **software radio (SR)** where the digitization is at (or very near to) the antenna and all (or very nearly all) of the processing required for the radio is performed by software residing in high-speed digital signal processors.

The software defined radio will occur in the near term migrating to the software radio in the longer term subject to the progression of core technologies.

In the above discussion and throughout this paper, the word "**digital signal processors** (DSP)" is used in a broad sense; therefore DSP includes field programmable gate arrays (FPGAs), reconfigurable computing (RC), etc.

Appendix B

Illustration of Software Radio Concepts

Figures B-1 and B-2 are provided to illustrate the conceptual definitions provided in Appendix A. The figures, because of the their generality, are equally applicable to either a commercial wireless handset or base station architecture. In the example in Figure B-2, the analog-to-digital (A/D) converter is placed after the intermediate frequency (IF) processing. As indicated in the figure, the radio baseband processing is under software control and a man-machine interface permits some manual input from the user. The architecture in this example is considered to be a software defined radio since some, but not all, of the signal processing is accomplished in software. It is of course possible for the digital baseband processing to be implemented in application-specific integrated circuits (ASICs), in which case the radio would be considered to be a digital radio but not a software defined radio.

If the A/D converter were to be moved closer to the antenna, the radio moves closer to the ideal, namely the software radio as defined above. This is illustrated in Figure B-2 which illustrates two concepts:

1. The software radio concept in which the digitization is nearly at the antenna.
2. The adaptive intelligent SR concept.

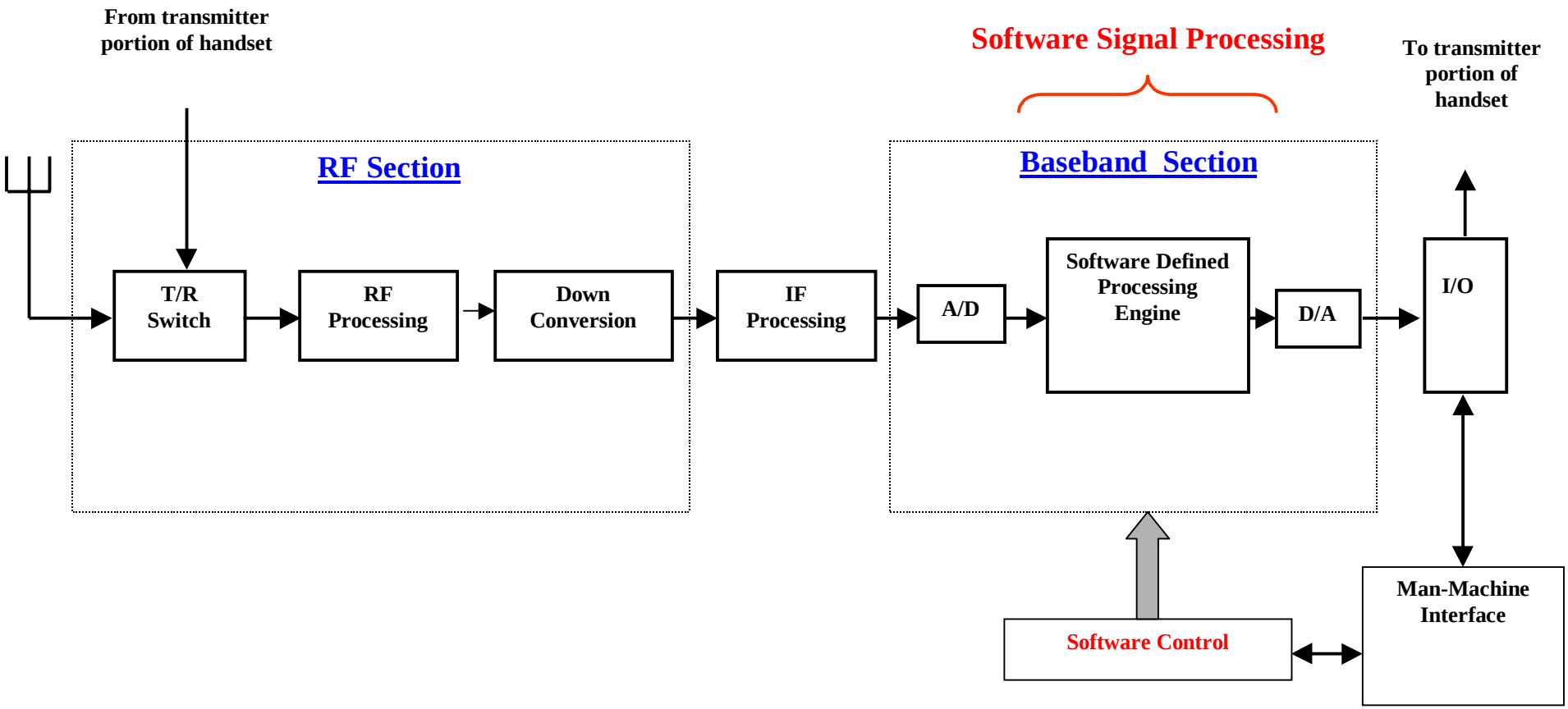
In Figure B-1, the A/D converter is immediately after the low noise amplifier and anti-aliasing filter; *i.e.*, the digitization is at RF. The other RF and IF processing is performed by the Wideband RF Front End Processing Engine. The intermediate case, which is not shown, would be between the architectures shown in Figures B-1 and B-2 in

which the there is direct digital conversion to baseband from RF thereby eliminating analog IF processing.

It can be expected that for the foreseeable future there will be a need for an analog low noise amplifier in the RF front end of the receiver and an analog final power amplifier in the RF portion of the transmitter - therefore, the ideal SR of an A/D converter right at the antenna appears to be unattainable in practice.

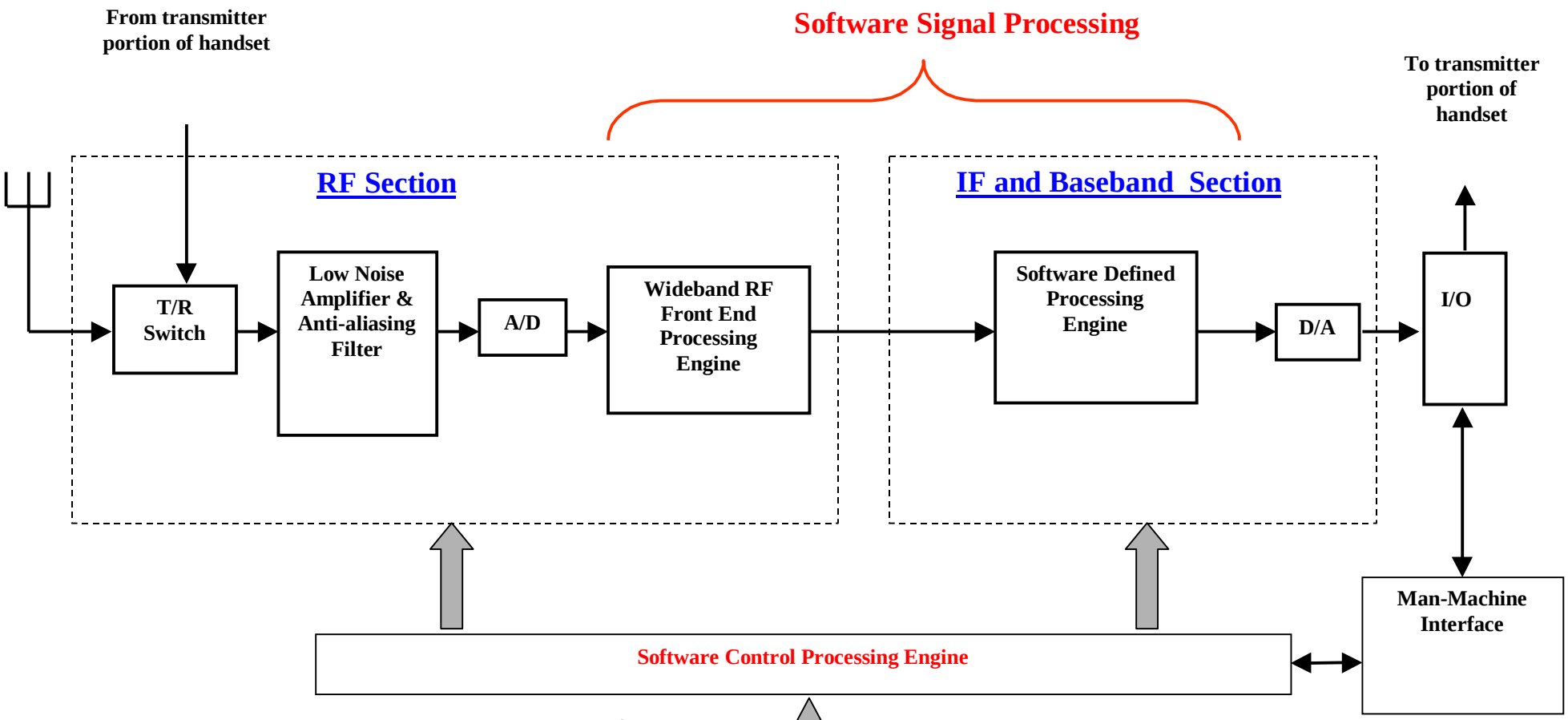
Figure B-2 also illustrates the concept of the adaptive intelligent software radio in which the radio has the capability of adapting to the operational environment. The RF front processing is under the control of a powerful software control processing engine. This software control processing implements the artificial intelligence and the processing is under that give the SR a truly adaptive capability. In the commercial wireless world, this is the type of processing that would be needed to achieve adaptive spectrum sharing, interruptible spectrum, spectrum-on-demand, or adaptive spectrum management. While this capability is a highly desirable goal, the research in the component parts needed to implement this capability is in the embryonic stages. Note the large number of inputs required including information from the mobile network infrastructure.

Figure B-1. An example of software defined radio based handset where only the baseband processing has been implemented in software.



Note:
This functional block diagram has been simplified for illustrative purposes.

Figure B-2. Example of the evolution of a software defined radio to a software radio with adaptive control.



- Information from mobile network infrastructure
- Available RF bands
- Available air protocols
- Propagation data
- User needs
- Minimum performance requirements
- Etc.

Note:
This functional block diagram has been simplified for illustrative purposes.