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

In the Matter of	)	
	)	
Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies	)	ET Docket No. 03-108
	)	
Authorization and Use of Software Defined Radios	)	ET Docket No. 00-47 (Terminated)
	)	

NOTICE OF PROPOSED RULE MAKING AND ORDER

Adopted: December 17, 2003 **Released: December 30, 2003**

Comment date: [75 days from publication in Federal Register]
Reply comment date: [105 days from publication in Federal Register]

By the Commission: Chairman Powell, Commissioners Copps, Martin and Adelstein issuing separate statements

Table of Contents Para No.

6 In a number of these areas, we propose specific rule changes to help enable devices using cognitive radio technologies. For instance, we set out a proposal under which unlicensed devices employing certain cognitive radio capabilities would be permitted to transmit at higher power levels in rural areas and other areas of limited spectrum use We also include a detailed technical model for spectrum leasing based on cognitive radio capabilities that would assure a licensee that it would be able to interrupt a lessee's use and reclaim spectrum in real time when the need arises. Such a model would appear to be most directly applicable to leasing by public safety entities if we decide to permit such leasing, but also important to other licensees interested in leasing spectrum. We also set out proposals to streamline our rules that require that a copy of certain devices' radio software be supplied to the Commission, to clarify when devices must be certified under the software defined radio rules, and to allow unlicensed devices to automatically select their transmit frequency band based upon the country of operation. Finally, in light of the initiation of this proceeding, we are closing the SDR proceeding of ET Docket No. 00-47.

7 In sum, we are seeking in this proceeding to facilitate opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies. We are seeking comment generally on how we should modify our rules to enable more effective use of cognitive radio technologies, including potential applications across a variety of scenarios involving both licensed spectrum and unlicensed devices We are also seeking comment specifically on the proposals set out below By initiating this proceeding, we recognize the importance of new cognitive radio technologies, which are likely to become more prevalent over the next few years and which hold tremendous promise in helping to facilitate more effective and efficient access to spectrum We seek to ensure that our rules and policies do not inadvertently hinder development and deployment of such technologies, but instead enable a full realization of their potential benefits.

II. BACKGROUND

8. Over the past several years, increasing attention has been paid to incorporating new computer processing capabilities into radio system technologies As recognized by the Commission and others in various procedural contexts, radio systems are increasingly incorporating software into radio system design, and are gaining increased abilities to be "cognitive"—to adapt their behavior based on external factors.[5] In addition, this Commission recently opened up additional opportunities for taking advantage of the potential of cognitive radio technologies in its secondary markets report and order.[6]

9 Radio manufacturers are incorporating software programming capabilities into radios that can make basic functions more easily changeable For more than a decade, most commercial radios have contained a microprocessor and software to control operating parameters such as frequency and modulation type, although the software installed at the factory was not readily changeable after manufacture A software defined radio (SDR) is a device in which the operating parameters are controlled by software, allowing the radio to be programmed to transmit and receive on a variety of frequencies and/or to use one or more different transmission formats supported by its hardware design Manufacturers are now producing radios in which the control software can be altered after the radio

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[5] *See In the matter of Authorization and Use of Software Defined Radios,* ET Docket No. 00-47, *Report and Order*, 16 FCC Rcd 17373 (2001)

[6] *See In the Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, WT Docket No 00-230, *Report and Order and Further Notice of Proposed Rule Making*, 18 FCC Rcd 20604 (2003)

3 Cognitive radio technologies can be used to improve spectrum access and efficiency of spectrum use under at least four possible scenarios. First, a licensee can employ cognitive radio technologies internally within its own network to increase the efficiency of use Second, cognitive radio technologies can facilitate secondary markets in spectrum use, implemented by voluntary agreements between licensees and third parties. For instance, a licensee and third party could sign an agreement allowing secondary spectrum uses made possible only by deployment of cognitive radio technologies. Ultimately cognitive radio devices could be developed that "negotiate" with a licensee's system and use spectrum only if agreement is reached between a device and the system. Third, cognitive radio technologies can facilitate automated frequency coordination among licensees of co-primary services. Such coordination could be done voluntarily by the licensees under more general coordination rules imposed by Commission rules, or the Commission could require the use of an automated coordination mechanism. Fourth, cognitive radio technologies can be used to enable non-voluntary third party access to spectrum, for instance as an unlicensed device operating at times or in locations where licensed spectrum is not in use

4 We undertake this proceeding to explore all the uses of cognitive radio technology to facilitate the improved spectrum use made possible by the emergence of the powerful real-time processing capabilities of cognitive radio technologies.[3] We also seek comment on how our rules and enforcement policies should address possible regulatory concerns posed by authorizing spectrum access based on a radio frequency (RF) device's ability to reliably gather and process real-time information about its RF environment or on the ability of device and/or users to cooperatively negotiate for spectrum access We propose and seek comment on rules intended to allow a full realization of the potential of these technologies under all our regulatory models for spectrum based services.

5 More specifically, in this *Notice* we first consider in some detail the technical capabilities that are or could be incorporated into cognitive radio systems and seek comment on possible additional capabilities We then address several specific applications of these technologies. These applications cut across the various scenarios discussed above. Among the various areas in which cognitive radio technologies may provide potential benefits are: permitting the use of higher power by unlicensed devices in rural or other areas of limited spectrum use, facilitating secondary markets in spectrum, enabling possible real-time frequency coordination (such as between NGSO satellite and other services), facilitating interoperability among different radio systems, and allowing for more extensive deployment of mesh networks. We finally consider our equipment authorization rules, and whether changes should be made to these rules to reflect the growing importance of cognitive radio technologies.[4]

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[3] *See* Commission Docket Created In Connection With OET Workshop on Cognitive Radio Technologies ET Docket No 03-108, *Public Notice*, DA 03-1480, (rel. May 2, 2003) (opening ET Docket No. 03-108)

[4] This proceeding is complementary to other Commission proceedings considering specific uses of cognitive radio technologies including. (1) additional spectrum for unlicensed devices in the 5470-5725 MHz frequency range, *In the matter of Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No 03-122, *Report And Order*, FCC 03-287 (rel. Nov 18, 2003) (*U-NII R&O*) We are not proposing any changes to the rules adopted in that proceeding. (2) additional spectrum for unlicensed devices below 900 MHz and in the 3 GHz band (the TV broadcast and 3650-3700 MHz bands), *In the Matter of Additional Spectrum for Unlicensed Below 900 MHz and in the 3 GHz Band*, ET Docket No 02-380, *Notice of Inquiry*, 17 FCC Rcd 25632 (2002), and (3) interference temperature, *In the matter of Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in the Fixed, Mobile and Satellite Frequency Bands*, ET Docket No 03-237, *Notice of Inquiry and Notice of Proposed Rulemaking*, FCC 03-289 (adopted Nov. 13, 2003)

00-47 to consider whether any changes to the rules were needed to accommodate SDR [13] Based on the comments received in response to the *Notice of Inquiry*, the Commission proposed certain changes to the equipment authorization rules for SDRs [14] The Commission adopted rule changes for SDRs in September 2001 that established a definition for SDR and a new procedure for obtaining approval for software changes to a radio, and required devices certified as SDRs to incorporate a means to prevent unauthorized modifications.[15] In adopting the rule changes, the Commission stated that it would consider whether more detailed security requirements were needed for SDRs at a later date and left the proceeding open. Because we are addressing possible changes to the SDR security and certification requirements in this proceeding, we are closing ET Docket No 00-47 without adopting any additional rules or changing any rules in that proceeding

13 The SPTF also considered the potential impact of cognitive radios on spectrum policy in its November 2002 Report.[16] It stated that while technological advances are contributing to the increased diversity of spectrum-based consumer applications, technological advances are also providing some potential answers to current spectrum policy challenges [17] Some recent and significant technological advances it noted include the increased use of digital technologies and the development of cognitive radio.[18] The SPTF specifically noted that cognitive radios can search the radio spectrum, sense the environment and operate in spectrum not used by others.[19] According to the SPTF, by operating in the so called white – or unused – spaces in the spectrum, cognitive radios can therefore enable better and more intensive use of the radio spectrum [20]

14. On May 19, 2003, the Commission held a workshop to explore state of cognitive radio technologies [21] The workshop explored the application of these new technologies to a variety of

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[13] *See Notice of Inquiry* in ET Docket No 00-47, 15 FCC Rcd 5930 (2000)

[14] *See Notice of Proposed Rule Making* in ET Docket No 00-47, 15 FCC Rcd 24442 (2000)

[15] *See First Report and Order* in ET Docket No 00-47, 16 FCC Rcd 17373 (2001)

[16] The SPTF sought comment to identify and evaluate possible spectrum policy changes and delivered its report to the Commission in November 2002 See "Commission Seeks Public Comment on Spectrum Policy Task Force Report," Public Notice, 17 FCC Rcd 24316 (2002) and *Task Force Report* at p 1-2 In this Notice, we use the term "cognitive radio" to describe the technologies discussed in the SPTF Report to improve spectrum use, including "software defined radio"

[17] *See Task Force Report* at 13

[18] *Id*

[19] *Id* at 14

[20] *Id* Commenters to the report generally supported exploring the benefits of cognitive radio technology in this regard *See generally*, Cingular Wireless, LLC Comments January 27, 2003; Cognio, Inc Comments January 27, 2003; Shared Spectrum Company Comments January 27, 2003 Others registered concern that the technology was still developmental *See generally* CTIA Comments January 27, 2003; New York Office of Technology Comments January 27, 2003

[21] *See* "The Office of Engineering and Technology hosting Workshop on Cognitive Radio Technologies May 19, 2003," ET Docket No 03-108, *Public Notice* (rel. May 16, 2003) We build on information obtained in that workshop in this proceeding

spectrum management scenarios including, secondary markets, public sector spectrum leasing, and new approaches for unlicensed operations in new and existing bands

15 The Commission currently has a pending proceeding that addresses cognitive radio technologies in specific applications The Commission adopted a *Notice of Inquiry* in December 2002 seeking comment on the possibility of allowing unlicensed operation in additional frequency bands, specifically, unused portions of the TV broadcast spectrum and the 3650-3700 MHz band.[22] In that proceeding, the Commission recognized that an unlicensed device operating in those bands would likely need to incorporate cognitive features to share spectrum without causing interference. Such features would include the ability to sense spectrum use or know where it is located in relation to other transmitters

16. Federal Government interest in cognitive radio technology has also been growing. For example, the Defense Advanced Research Projects Agency (DARPA) is administering the neXt Generation (XG) Communication program [23] This program is developing technology to allow, through adaptive techniques, multiple users to share common spectrum, yet avoid conflicts in time, frequency, code, and other signal characteristics The goal of the XG program is to enable a spectrum usage increase of a factor of ten and achieve easier global regulatory compliance. The program is intended to develop technology that is applicable to both military and civilian use. DARPA issued two requests for comments in the XG program one concerning the program's overarching view of adaptive spectrum communications, and the other concerning the main features of XG protocols, interfaces, behavior sets,[24] and spectrum access policies [25] DARPA states that three more requests for comments will be issued in the near future that provide more detailed descriptions of the XG features outlined in the previously issued request for comments [26]

17. In the international arena, other administrations are considering the impact of cognitive radio technologies For example, the agenda for the 2007 World Radiocommunication Conference (WRC-07) will consider frequency-related matters for the future development of International Mobile Telecommunications-2000 (IMT-2000) and systems beyond IMT-2000, taking into account the results of ITU-R studies in accordance with Resolution 228, as modified at the 2003 World Radiocommunication Conference (WRC-03) [27] In particular, these ITU-R studies will be looking at the evolution of IMT-2000

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[22] *See Notice of Inquiry* in ET Docket No 02-380, 17 FCC Rcd 25632 (2003)

[23] Information on the XG program is available at www darpa mil/ato/programs/XG/.

[24] Five abstract behavior sets have been identified for XG sensing, identification, dissemination, allocation, and use or opportunities

[25] *See* http //www darpa.mil/ato/programs/xg/rfcs htm

[26] *Id*

[27] *See* Resolution 802, WRC-03, agenda item 1 4 IMT-2000 is a set of technical standards developed by the ITU to foster the development of third generation (3G) and future advanced wireless systems For a description of the system characteristics and capabilities of IMT-2000 systems, see the FCC Staff Final Report, "Spectrum Study of the 2500-2690 MHz Band The Potential for Accommodating Third Generation Mobile Systems," March 30, 2001, available at http //www fcc.gov/3G/

and pre-IMT-2000 systems through advances in technology, such as adaptive antennas and software defined and cognitive radio technology [28]

III. DISCUSSION

18 Many of today's radio systems contain microprocessors and can, or could be programmed to, change their transmission characteristics based on their operating environment. The techniques used to do this encompass a variety of technologies. For example, some devices can automatically select an unoccupied frequency based on detection of the frequencies currently in use, or can raise or lower their output power to establish a link or to save battery power. Advances in technology and, in particular, the ability to rely on software changes to modify radio operations as needed, suggest that we should not attempt to regulate cognitive radio technology in a way that could limit its potential. Instead, it is preferable that we understand the types of capabilities that cognitive radio technology could provide and how cognitive radio technology could benefit the Commission's spectrum management functions We intend to look broadly at these issues, yet we also recognize that technology is often designed to address specific objectives We also recognize that cognitive radio technology could raise new interference issues that will need to be considered. We expect that cognitive radio technology's scope of capabilities and techniques will evolve, and all of features need not be present in a given application for the radio to be deemed "cognitive." With this broad analytic approach, we hope to be in a better position to determine how the use of cognitive radio technology could benefit our regulatory processes for a given application.

19 In this Notice, we first explore the benefits of cognitive radio technology use for spectrum management and regulation and the broad capabilities that such technology could encompass We intend to use this framework for further analysis of specific applications of this technology. We also seek comment and set forth proposals regarding specific applications rural markets and unlicensed devices, public sector spectrum leasing, dynamically coordinated spectrum sharing, interoperability between communication systems, and mesh networks We are further proposing changes to our equipment authorization processes to accommodate software-defined radios and cognitive radio systems

A. Cognitive Radio Capabilities

20 Cognitive radio technologies have the potential to provide a number of benefits that would result in increased access to spectrum and also make new and improved communication services available to the public A cognitive radio could negotiate cooperatively with other spectrum users to enable more efficient sharing of spectrum. A cognitive radio could also identify portions of the spectrum that are unused at a specific time or location and transmit in such unused "white spaces," resulting in more intense, more efficient use of the spectrum while avoiding interference to other users.[29] Cognitive radio technology could also be used to facilitate interoperability between or among communication systems in which frequency bands and/or transmission formats differ. For example, cognitive radio could select the appropriate operating frequency and transmission format, or it could act as a "bridge" between two systems by receiving signals at one frequency and format and retransmitting them at a

[28] These issues have been jointly assigned to Working Parties 8A and 8F

[29] *See, e g*, FCC Cognitive Radio Workshop, "Frequency Agile Spectrum Access Technologies," Presentation by Mark McHenry, Shared Spectrum Company (May 19, 2003)

different frequency and format.[30] Cognitive radio technology can also help advance specific Commission policies, such as facilitating the use of secondary markets in spectrum and improving access to spectrum in rural areas [31]

21. Cognitive radio systems can be deployed in network-centric, distributed, ad hoc, and mesh architectures, and serve the needs of both licensed and unlicensed applications For example, cognitive radios can function either by employing cognitive capabilities within a network base station that in turn controls multiple individual handsets or by incorporating capabilities within individual devices.

22 There are a number of capabilities that can be incorporated into cognitive radios. A first is frequency agility, which is the ability of a radio to change its operating frequency, combined with a method to dynamically select the appropriate operating frequency based on the sensing of signals from other transmitters or on some other method. A second is adaptive modulation that can modify transmission characteristics and waveforms to exploit opportunities to use spectrum.[32] A third capability is transmit power control, which allows transmission at the allowable limits when necessary, but reduces the transmitter power to a lower level to allow greater sharing of spectrum when higher power operation is not necessary. A fourth capability that a cognitive radio could incorporate is the ability to determine its location and the location of other transmitters, and then select the appropriate operating parameters such as the power and frequency allowed at its location Fifth, a cognitive radio could incorporate a mechanism that would enable sharing of spectrum under the terms of an agreement between a licensee and a third party Parties may eventually be able to negotiate for spectrum use on an ad hoc or real-time basis, without the need for prior agreements between all parties. In addition to these capabilities, any SDR, including a cognitive radio, could incorporate security features to permit only authorized use and prevent unauthorized modifications. We seek comment on what other features and capabilities a cognitive radio could incorporate.

23 While cognitive radios could incorporate all of the capabilities listed above and possibly others, the types of technologies that would need to be employed in a particular device would vary based on the frequency bands where the equipment is deployed and the types of services authorized to operate in those bands. Multiple capabilities may in all likelihood be used simultaneously in cognitive processing For example, devices sensing unused spectrum may rely on frequency agility in selecting their band of operations and adaptive modulation techniques in setting the power, frequency and type of signal transmitted Devices might further manage their signals with the location of themselves and other transmitters in mind Negotiations and exchanges with other users might also occur, contributing to the increased efficiency and reduction of interference for all spectrum users We review each of these

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[30] *See* Intel Corporation Reply, ET Docket No 02-380 at 14-18 (May 16, 2003), *see also* FCC Cognitive Radio Workshop, "Cognitive Radio Technologies in the Public Safety & Governmental Arenas," Presentation by Dr. Mike Marcus, Associate Chief, Office of Engineering and Technology, FCC (May 19, 2003)

[31] *See* In the Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, *Report and Order and Further Notice of Proposed Rulemaking*, FCC 03-113 at 88, 103, para 232, 291 (rel Oct 6, 2003) (*Secondary Markets R&O/FNPRM)*; Facilitating the Provision of Spectrum-Based Service to Rural Areas and Promoting Opportunities for Rural Telephone Companies to Provide Spectrum-Based Services, *Notice of Proposed Rulemaking*, FCC 03-222 at 27, para. 50 (rel Oct 6, 2003) (*Rural NPRM*)

[32] Hetereomorphic waveforms and other new techniques would allow two or more waveforms to co-exist by using different polarity, code, orthangonality, etc

capabilities below and seek comment how cognitive radio capabilities might function together to achieve spectrum access, efficiency and interference mitigation.

24 Dynamic frequency selection (DFS) is defined in the rules as a mechanism that dynamically detects signals from other radio frequency systems and avoids co-channel operation with those systems [33] This term was developed in the context of unlicensed devices to refer to a technique that uses spectrum sensing and frequency selection technology to avoid interference to radar systems. We will use this term in the context of cognitive radio to more broadly refer to a mechanism that selects an appropriate operating frequency for a device based on some specific condition. The conditions could include, for example· the location of the device, its proximity to other devices, the presence or absence of a beacon signal indicating whether use of certain frequencies is permitted by a licensee, or an operating requirement to adjust power to the minimum needed to establish a reliable communication link. Alternatively, a device could change the polarization of its antenna to allow two devices to share the same frequency, with one device using one polarization and the other using a different polarization The methods that a device could use to decide when to change frequency or polarization could include spectrum sensing, geographic location monitoring, or an instruction from a network or another device. Spectrum sensing may be appropriate in bands for example, where services may transmit for long periods of time, *e g* , broadcast type services, and sensing techniques would not need to be repeated frequently to be effective In other services where transmissions occur on an intermittent basis, sensing may be needed more often In the case of unlicensed devices operating in the 5470-5725 MHz frequency range, the Commission requires continuous sensing to prevent interference.

25 There are techniques that can be used to increase the ability of a sensing receiver to reliably detect other signals in a band which rely on the fact that it is not necessary to decode the information in a signal to determine whether a signal is present For example, the use of specialized detectors can improve the ability to sense the presence of other signals by 30-40 dB.[34] Most applications of signal detection in commercial practice are based on "radiometric detectors" which only function if the signal is greater than the noise level in the receiver system However, in the past decade information has become available about an alternative technology called cyclostationary detectors or feature detectors which use longer sensing times and internal computation to achieve signal sensitivities below the noise level for signals of known format By processing a large number of transmitted symbols, without the need to demodulate them individually, such a feature detector can achieve a processing gain over a radiometric detector which does not use knowledge of the signal format. In practice, processing gains of 30-40 dB can be achieved with computation resources typical of today's microprocessors. With such a detector capable of receiving signals more than 30 dB below the noise floor the hidden node problem[35]

[33] *See* 47 C F R § 15 403(g)

[34] The Commission has held tutorials discussing the use of feature detectors and commenters have described the application of these techniques to various spectrum sharing scenarios *See* John W. Betz, PhD, Feature Detection, (Feb 12 2003), *available at* http //www fcc gov/realaudio/presentations/2003/021203/featuredetection pdf, *see also* Shared Spectrum Company, Hidden Node Problem Discussions, *ex parte* (Sep 25, 2003), *available at* http //fccweb01w/prod/ecfs/retrieve cgi?native_or_pdf=pdf&id_document=6515182975 Dr. Betz's presentation contains a detailed bibliography of academic publications on the subject.

[35] The hidden node problem refers to the case of a signal that reaches a desired receiver near the sensor, but is undetected at the sensor due to local terrain features that block it from the sensor An example might be a TV signal which is received at an antenna on top of a building whereas building shadowing prevents a ground level radiometric detector from detecting the signal since the signal strength in the shadow is very weak. In such a case use of a small co-channel transmitter at the sensor site might result in interference to the higher TV antenna The (continued)

that might result in missing the presence of a signal becomes much less likely than with radiometric detectors

26 Adaptive modulation techniques can modify transmission characteristics and waveforms to provide opportunities for improved spectrum access and more intensive use of spectrum while "working around" other signals that are present A cognitive radio could select the appropriate modulation type for use with a particular transmission system to permit interoperability between systems For example, it could switch between different channel access schemes such as time division multiple access (TDMA) and code division multiple access (CDMA) depending on the type of system in use [36] Other possible uses of adaptive modulation include dynamically selecting the transmission bandwidth based on the availability of spectrum and the desired transmission data rate In addition, new types of modulation may be possible in a cognitive radio, such as splitting a signal to occupy multiple non-contiguous frequency bands simultaneously. For example, using "heteromorphic" waveforms and other techniques, open spaces in spectrum can be identified and accessed based on a variety of factors [37] Heteromorphic waveforms can use gaps in spectrum based on time, space, power, frequency, bandwidth, data rate, modulation, coding or other characteristics

27 Transmit power control (TPC) is a feature that enables a device to dynamically switch between several transmission power levels in the data transmission process. This feature has long been incorporated into various communication systems and devices. The term TPC will be used broadly to refer to a mechanism that switches the output power of a device based upon specific conditions. The conditions could include the proximity to other devices, the maximum power permitted at a geographic location, or an operating requirement to adjust power to the minimum needed to establish a reliable communication link

28 A cognitive radio could incorporate the capability to determine its location and the location of other transmitters, and then select the appropriate operating parameters such as the power and frequency allowed at its location. This could be done by using a geo-location technique such as GPS to determine the geographic location, and then accessing a database incorporated in a device or by accessing a database over a network. In bands such as those used for satellite downlinks that are receive-only and do not transmit a signal, location technology may be an appropriate method of avoiding interference because sensing technology would not be able to identify the locations of nearby receivers

29. A cognitive radio could incorporate a mechanism that would enable sharing of spectrum under the terms of an agreement between a licensee and a lessee. Because this capability is best explained in conjunction with spectrum leasing, it is discussed below in the section on secondary markets

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use of a feature detector much more sensitive than the TV receiver (which requires a signal 10-20 dB **above** the noise level) makes this much less likely

[36] In a time division multiple access (TDMA) system, the same frequency is shared by multiple users The frequency is divided into time slots, with each user transmitting for one time slot and then remaining silent for a specific number of time slots In a code division multiple access (CDMA) system, multiple users can also operate simultaneously in a frequency band Each user's signal is coded, which allows a receiver with the corresponding code to hear the desired signal There are many variations of TDMA and CDMA systems in use

[37] *See generally* Scott Seidel, Robert Breinig, Robert Berezdivin, Adaptive Air Interface Waveform for Flexibility and Performance in Commercial Wireless Communications Systems, presentation to the World Wireless Research Forum, March 8, 2002

30. While the capabilities described above can enable cognitive radios to use spectrum more efficiently, relying on these capabilities in a radio raises the possibility of new types of abuse A GPS receiver in a radio could be re-programmed with a geographic offset that would make the radio behave as though it were at a location far from its actual location. Additionally, databases used to determine the location of other transmitters and/or receive sites could be altered so a device would not "know" about the presence of other users that require protection from interference. Further, software used to select the appropriate operating parameters could be altered to make a radio transmit at frequencies, power levels or locations where it should not We are seeking comment below on how best to enable cognitive radio technologies while taking these issues into account. In addition, there are technologies that could possibly be used to address some of the device security concerns described above, as well as problems in communications security. Both the computer and consumer electronics industries have begun to address such problems of "trusted computing" and how to secure a device against both tampering by third-parties as well as unauthorized modifications by its owner Evolving technologies address problems like third-parties eavesdropping on private communications, tampering with messages in transit, or misrepresenting a sender's identity (spoofing) in a non-secure communication [38] In the network computing context, technologies are available that can provide a "peer enforcement" mechanism; a feature allows a device to identify other users or systems operating outside of specific parameters In the RF radio context, our concern has been that a transmitter with unauthorized software modifications could violate Commission rules and thereby potentially interfere with other services Manufacturers may be able to adapt "peer enforcement" constructs to cognitive radios and these new features may minimize the need for direct Commission involvement. In addition to a "peer enforcement" mechanism that identifies radios operating in violation of the Commission rules, new security technologies could allow development of time-limited licensing schemes which could ensure that devices are regularly updated to maintain compliance with our rules If, for instance, a device were to have to connect to a manufacturer's web site periodically in order to retain the right to operate, certain assurances could be made about the validity of the device's operating parameters and the control software for those parameters.

31 We seek comment on all issues related to the application of cognitive radio technology, including the frequency bands and services that are most likely to benefit from this technology. We conclude that we should continue to prohibit unlicensed devices from emitting in designated restricted bands,[39] which include many bands used for Federal Government operations, and seek comment on this tentative conclusion

32. The capabilities that can be employed in cognitive radios could be applied in a variety of specific applications and could bring about significant changes in how people approach the use of spectrum. As we discuss below, some applications could make more efficient use of spectrum and others could facilitate the introduction of new uses. Some applications could likely be introduced under existing rules, whereas other applications may require specific rule changes, as we discuss in more detail below

[38] *See generally* John W Rittinghouse and William M Hancock, *Cybersecurity Operations Handbook* (2003), Limor Elbaz, Using Public Key Cryptography in Mobile Phones, White Paper, Discretix Technologies Ltd. (October 2002), available at http //www discretix com/white_paper_c3 pdf.

[39] *See* 47 C F R § 15 205 Unlicensed devices may not intentionally transmit in these bands

B. Application: Rural Markets and Unlicensed Devices

1. Background

33. In its Report, the Spectrum Policy Task Force recommended that the Commission explore ways to improve access to spectrum in rural areas.[40] The Commission recently adopted a *Notice of Proposed Rule Making* to consider proposals for facilitating access to spectrum based services in rural areas.[41] This *Rural Services Notice* addresses licensed spectrum use, and states that the Commission will consider unlicensed spectrum use in rural areas in a separate proceeding.[42] We note that the *Rural Services Notice* seeks comment on a definition of rural areas [43]

34 The lower population density and the greater distances between people in rural areas can make it difficult for certain types of unlicensed operations at the current Part 15 limits to provide adequate signal coverage Such operations include Wireless Internet Service Providers (WISPs) and wireless LANs operated between buildings or other locations with a large separation between transmitters These operations could potentially benefit from higher power limits in rural areas, which would result in greater transmission range. Because spectrum is generally not as intensively used in rural areas, it may be possible for unlicensed devices to operate at higher power levels in those areas without causing harmful interference to authorized services The application of cognitive radio technology could help ensure that devices limit their higher power operation to only rural areas.

35. Devices such as transmitters used by WISPs and wireless LANs often operate under the Part 15 spread spectrum rules in Section 15.247.[44] In addition, any type of operation (*e g.*, cordless phones, wireless cameras, fleet management devices) is permitted in certain bands under Section 15.249 [45] The power limits currently permitted vary depending on the frequency band and in some cases the signal characteristics, such as the number of hopping channels for spread spectrum devices

2. Discussion

36. Permitting unlicensed devices to operate at higher power levels in rural areas could help provide improved access to spectrum in those areas by permitting greater transmission range and therefore greater coverage areas. Accordingly, we propose to allow higher power operation for certain types of unlicensed devices in circumstances, as discussed below, that should benefit consumers in rural areas. We note that while licensed devices are typically licensed for use in a specified geographic area at a specific maximum power level, unlicensed devices generally have no geographic restrictions on operation and can be used in any location Because spectrum use in rural areas is generally extremely low, measuring spectrum occupancy is a method that could potentially be used to determine when a

[40] *See Task Force Report* at 58

[41] *See generally Rural NPRM* at 7, para 10

[42] *Rural NPRM* at 27, para 50

[43] *See generally Rural NPRM* at 7, para 10

[44] *See* 47 C F.R §§ 15 247 The spread spectrum rules allow operation in the bands 902-928 MHz, 2400-2483 5 MHz and 5725-5850 MHz

[45] *See* 47 C.F R § 15 249 This section allows operation in the bands 902-928 MHz, 2400-2483 5 MHz, 5725-5875 MHz and 24 0-24.25 GHz

device is in a rural area and is eligible to operate at higher power. We propose to permit higher power operation by unlicensed devices in any area that has limited spectrum use, provided the device has capabilities to determine whether it is in an area with limited spectrum use This proposal will benefit persons living in rural areas as well as persons living in other areas that may be underserved by spectrum based services

37. We propose to implement these changes by adding a new rule section that applies specifically to cognitive radio devices operating in the industrial, scientific and medical (ISM) bands on the frequencies specified in Sections 15 247 and 15.249 of the rules. This proposed rule section would permit higher power operation for cognitive devices than these sections currently allow, provided that the devices meet all the other requirements of Sections 15.247 and 15 249, and that the devices incorporate certain features to determine that they are in an area with limited spectrum use. We also propose to require that unlicensed devices capable of higher power operation in areas of limited spectrum use incorporate TPC capabilities that, when the device is operating at greater than 1 Watt, will limit its power output to the minimum level necessary for reliable communications. We do not propose any changes to the current Sections 15 247 and 15 249 for non-cognitive radio devices. The proposed rule for cognitive devices references all the current requirements in these sections at this time, which include requirements for spread spectrum systems to use specific channel spacings, channel bandwidths, power spectral density or number of hopping channels.[46] These requirements were established to facilitate spectrum sharing with licensed services and between unlicensed operations. However, in areas where spectrum use is low, all of the current requirements in the spread spectrum rules to facilitate spectrum sharing may not be necessary due to the limited number of users in such areas. Because cognitive devices could determine when spectrum is in use and avoid transmission on those frequencies, it may be possible to relax some of the current requirements in the rules in addition to raising the maximum power for cognitive devices operated in areas with limited spectrum use without causing interference to other users

38 We propose to allow a transmitter power increase of up to 6 times (approximately 8 dB) higher than the current limits in the 902-928 MHz, 2400-2483.5 MHz and 5725-5850 MHz bands under Section 15 247 of the rules, and in the 902-928 MHz, 2400-2483.5 MHz, 5725-5875 MHz and 24 0-24.25 GHz bands under Section 15 249 of the rules [47] This increase is consistent with the Commission's recent proposal in ET Docket 03-201 to permit a power increase of 8 dB for spread spectrum systems using sectorized antennas [48] This prop would increase the signal range by a factor of up to 2 5 and increase the coverage area by a factor of six as compared to the current limits, which would be particularly beneficial for wireless LAN and WISP uses [49] Specifically, the proposed maximum transmitter power levels or maximum field strength levels in areas with limited spectrum use would be:

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[46] *See* 47 C F R § 15 247(a) Section 15 249 does not contain operational requirements comparable to those for spread spectrum devices because the maximum power permitted under Section 15 249 is significantly lower than the maximum permitted for spread spectrum devices, thus significantly reducing the potential for interference.

[47] Devices operating under Section 15.249 must comply with field strength limits rather than power limits An increase of 8 dB corresponds to a 2.5 times increase in field strength

[48] *See Notice of Proposed Rule Making* in ET Docket No 03-201, 18 FCC Rcd 18910 (2003).

[49] The power at a receiver is a function of the transmit power, the propagation (or path) loss between the transmitter and receiver, and the receive antenna gain That is

Received power = transmit power – path loss + receive antenna gain

(continued)

a Spread Spectrum Devices (§ 15.247)
   - 6 watts for digital transmission systems and the following frequency hopping systems: systems in the 2400-2483.5 MHz band using at least 75 hopping channels, all systems in the 5725-5850 MHz band and systems in the 902-928 MHz band using at least 50 hopping channels
   - 1 5 watts for frequency hopping systems in the 902-928 MHz band using at least 25, but fewer than 50 hopping channels
   - 0.75 watts for frequency hopping systems in the 2400-2483.5 MHz band using fewer than 75 hopping channels

b Unlicensed operation in the 900 MHz, 2 4 GHz, 5.8 GHz and 24 GHz bands (§ 15.249)
   - 125 millivolts per meter at a distance of 3 meters in the 902-928 MHz, 2400-2483 5 MHz and 5725-5875 MHz bands
   - 625 millivolts per meter at a distance of 3 meters in the 24.0-24.25 GHz band

39. We note that all of the bands where higher power operation is proposed are allocated on a primary basis for ISM equipment, which is generally not susceptible to interference from other devices.[50] However, each of these bands is also used by licensed services that are entitled to protection from interference by Part 15 devices For example, the 902-928 MHz band is used by the Location and Monitoring Service (LMS),[51] and all of these bands are used by Amateur Radio licensees Because we are proposing to both limit higher power operation to areas with limited spectrum use and require devices to sense spectrum use before commencing transmissions, we believe that implementation of this proposal would not significantly increase the interference potential to licensed services that operate in one or more of the subject ISM bands. We seek comment on this view We also seek comment on whether any particular licensed uses of these bands or portions thereof should receive greater protection or be excluded from this proposal? For example, the 2400-2402 MHz band is used by the Amateur Satellite

(Continued from previous page)

If the transmit power is increased by a factor of six (8 dB), then the path loss between the transmitter and receiver could be increased by 8 dB and result in the same received power An 8 dB increase in path loss corresponds to an increase in the separation distance between the transmitter and receiver by a factor of 2 5, assuming no other path losses due to factors such as terrain, foliage, buildings or atmospheric conditions The increase in coverage area is proportional to the square of this distance, which is a factor of approximately six, assuming an omni-directional transmit antenna and a circular coverage area

[50] *See* 47 C F R § 2 106, International footnote 5 150, stating that radio communication services operating in certain bands, including the 902-928 MHz, 2400-2500 MHz, 5725-5875 MHz and 24-24 25 GHz bands, must accept interference received from ISM applications The ISM bands are also listed in 47 C.F R § 18 301. ISM equipment uses radio frequency energy to perform work such as heating or lighting rather than communications *See* 47 C F R § 18 107(c) Examples of ISM equipment include microwave ovens, industrial heating equipment, and RF lighting devices Because ISM equipment does not perform communication functions, it is not susceptible to interference from RF communication devices

[51] We also note that spectrum in the 902-928 MHz band dedicated for licensed use by the multilateration Location and Monitoring Service (M-LMS) is the subject of a pending petition for rulemaking filed by Progeny LMS, LLC *See* "Wireless Telecommunications Bureau Seeks Comment On Petition For Rulemaking Regarding Location And Monitoring Service Rules," *Public Notice*, DA 02-817, 17 FCC Rcd 6438 (WTB rel Apr 10, 2002), *see also* "Wireless Telecommunications Bureau Extends Comment Cycle On Petition For Rulemaking Regarding Location And Monitoring Service Rules," *Public Notice*, DA 02-1070, 17 FCC Rcd 8377 (WTB rel. May 7, 2002) (extending the deadline for comments on the petition)

Service, which we have noted is potentially more vulnerable to aggregate interference than other applications.[52]

40 We seek comment on these proposals, including whether higher power operation should be permitted in all frequency bands under Sections 15 247 and 15 249 of the rules, and whether there should be any restrictions on the applications or types of devices that may operate at higher power. We also seek comment on whether there are any requirements currently in the rules that could be relaxed or eliminated for cognitive radio devices For example, in addition to the requirements for spread spectrum devices noted above, Section 15.247(h) contains a provision that prohibits the synchronization of the timing of hop sets in a non-cognitive way to prevent a group of devices from monopolizing the use of the spectrum and blocking other devices from transmitting [53] Could this section be eliminated for cognitive devices without adversely affecting spectrum sharing? We also seek comment on whether we should exempt devices operating under the control of a master controller from complying with DFS or other requirements [54]

41 We further seek comment on whether higher power operation should be permitted for devices operating under any other sections in Part 15. For example, Section 15.209 allows operation at a low level in almost any frequency band other than the TV bands and certain designated restricted bands [55] Should higher power operation be allowed under that section? We seek comment on whether the increased levels we are proposing are sufficient to be of benefit to WISPs, wireless LANs or other unlicensed operations in areas with limited spectrum use, and how much of an increase in service area these levels would allow in practice. We also seek comment on whether these power increases are likely to result in interference to other users, and the sufficiency of our proposal that TPC be used to ensure that these higher power unlicensed devices satisfy the applicable power limits – both inside and outside areas of limited spectrum use.

42 We propose that devices operating under the new rule section comply with the same harmonic and out-of-band emission limits as devices operating under Sections 15.247 and 15.249 of the rules The current harmonic emission limits for devices operating under Section 15.249 are independent of the in-band power. Theses limits are 500 microvolts per meter at a distance of three meters for devices operating in the 902-928 MHz, 2400-2483.5 MHz and 5725-5875 MHz bands, and 2500 microvolts per meter at a distance of three meters for devices operating in the 24.0-24.25 GHz band [56] The out-of-band

[52] *See* Amendment of Parts 2 and 97 of the Commission's Rules to Create a Low Frequency Allocation for the Amateur Radio Service, *Report and Order*, ET Docket No 02-98, 18 FCC Rcd 10258 (2003), paras 43-44

[53] *See* 47 C F R § 15 247(h) This section states that the incorporation of intelligence in frequency hopping spread spectrum systems is permitted if it allows the system to individually and independently choose and adapt its hopsets to avoid hopping on occupied channels. The coordination of frequency hopping systems in any other manner for the express purpose of avoiding the simultaneous occupancy of individual hopping frequencies by multiple transmitters is not permitted

[54] A master device was defined in the U-NII proceeding as a device operating in a mode in which it has the capability to transmit without receiving an enabling signal In this mode it is able to select a channel and initiate a network by sending enabling signals to other unlicensed U-NII devices *See U-NII R&O* at Appendix C.

[55] *See* 47 C F R §§ 15 209 and 15 205 The Commission recently proposed to allow unlicensed devices to operate on unused channels in the TV bands That issue will be addressed in a separate proceeding. *See Notice of Inquiry* in ET Docket 02-380, 17 FCC Rcd 25632 (2002)

[56] *See* 47 C F R. § 15 249

emission limit for devices operating under Section 15 249, 50 dB below the in-band emission limit, is a function of the in-band field strength[57] For devices operating under Section 15.247, the limit for out-of-band emissions that fall within designated restricted bands is also independent of the in-band power[58] However, the Section 15.247 limit for out-of-band emissions that fall outside restricted bands, 20 dB below the in-band power, is a function of the in-band power We seek comment on whether we should adjust the limits so that out-of-band emissions from equipment operating at higher power levels are no greater than the current rules allow. Additionally, we note that the 2400-2483 5 MHz band is adjacent to the mobile satellite service downlink band at 2483.5-2500 MHz We seek comment on the effect that raising the power of unlicensed devices could have on satellite receive terminals in the adjacent band[59]

43. Also, we note the presence of federal radiolocation operations in the 5725-5925 MHz frequency band. The Department of Defense operates fixed, transportable and mobile radars that are used primarily for surveillance, test range, instrumentation, airborne transponders, and experimental testing These radars are used extensively in support of national and military test range operations in the tracking and control of manned and unmanned airborne vehicles Many of the installations where these radars operate are located in rural areas We seek comment on the potential effects of our proposal, including its cognitive radio safeguards, on such federal radiolocation operations

44 As discussed above, we propose that unlicensed devices be permitted to operate at higher power in areas with limited spectrum use. We propose that limited spectrum use be defined as the authorized band of operation, *e g.*, the 2400-2483.5 MHz band, having a certain percentage of spectrum unused We propose to define "unused spectrum" for this purpose as spectrum with a measured aggregate noise plus interference power no greater than 30 dB above the calculated thermal noise floor within a measurement bandwidth of 1.25 MHz, which is the same value specified for unlicensed PCS devices.[60] We also propose that a device must be able to sense across the entire authorized band of operation to determine spectrum occupancy before commencing transmissions at higher power. We seek comment on these proposals, including the specific percentage of spectrum that must be vacant for a band to be considered "empty enough" to allow higher power transmission. We seek comment on the specific 30 dB monitoring threshold level proposed in these bands.[61] Because some devices that operate in the spread spectrum bands hop frequency and may not be on a particular frequency at a given instance in time, we seek comment on how long a device must sense a band of spectrum to determine it is unused before the device can transmit at higher power. We also seek comment on the type of receive antenna that should be used in measuring spectrum occupancy, whether the proposed monitoring threshold is reasonable and how wide a frequency band should be monitored to make this determination. We further

[57] *See* 47 C F R § 15 249(d) This section does not require out-of-band emissions to be attenuated below the levels in 47 C F.R § 15 209

[58] *See* 47 C F R § 15.247(c) Certain bands are designated as restricted bands under Part 15 of the rules. Only spurious emissions are permitted in restricted bands, and the levels must not exceed the emission limits in Section 15 209 *See* 47 C F R §§ 15.205 and 15 209

[59] The 2483 5-2500 MHz band is a restricted band, and the proposed rules would not change the current emission limit in this band

[60] *See* 47 C F R § 15 323(c)(2) This section specifies a monitoring threshold of 30 dB above the thermal noise floor for a bandwidth equivalent to the emission bandwidth for a device. While a precise emission bandwidth is not specified, this section specifies channel bandwidths of 1 25 MHz

[61] Other numbers may well be appropriate in bands with other sharing scenarios.

seek comment on the capabilities a device needs to determine when spectrum is empty enough, whether the required capabilities are achievable now or in the near future, and whether they could be economically incorporated into devices.

45. We propose to require that unlicensed devices operating at higher power levels continue to comply with the current RF safety requirements.[62] We recognize that although it may be relatively easy for a WISP provider to increase its power, for instance, from a central base station, a user's ability to increase its power on the return path may be constrained due to battery or RF safety issues. However, the use of properly designed sectorized receive antennas, coupled with their inherent gain, at the central site could overcome this perceived limitation. We seek comment on whether there are any possible problems with unlicensed devices operating at higher power levels meeting the RF safety limits

46 It seems apparent that allowing some devices in a band to operate with higher power could block the use of lower power devices, resulting in a situation where certain devices would not be able to operate We therefore seek comment on whether a device operating at higher power should have to re-sense spectrum use at periodic intervals to determine whether other users are attempting to transmit If so, how often should it re-sense? Would such a requirement have undesirable effects, such as requiring a WISP to lower power or turn off completely, and possibly lose a connection when another device such as a cordless telephone comes on the air, or causing users of lower power devices to simply cease operating if they received interference? Alternatively, should there be a requirement for devices operating at a higher power level to shut down for some period of time at a set interval to allow an opportunity for other devices to access spectrum? If so, what would be the appropriate time intervals?

47 We seek comment on alternative methods, such as geo-location, that a device could use to determine if it is in a rural area, and whether a combination of techniques should be required. If a cognitive radio device relied on geo-location, we would defer to WTB Docket No. 03-202 for an appropriate definition of rural area[63] We seek comment in this docket on the positional accuracy necessary if a geo-location technology such as GPS were used. How would a device using geo-location access a table or database showing where operation is permitted, and who would be responsible for maintaining the database? Should the geo-location technology be required to be incorporated within the device? How would the device react if it were unable to determine its exact position, for example, if it were to be indoors? Could some surrogate method, such as measuring the number of AM or FM broadcast signals in an area prove useful as an alternative optional method for identifying an area that is sparsely populated from a spectrum perspective where higher power operation could be permitted? We also seek comment on whether alternative approaches such as registration should be permitted to authorize operation under higher power limits in rural areas. Finally, we seek comment on whether there are any special enforcement issues when cognitive radio technologies are used to permit the higher power operation we have proposed.

C. Application: Secondary Markets

1. General

48. We recently took several steps in the *Secondary Markets Report and Order and Further Notice (Secondary Markets Order)* to facilitate and streamline the ability of spectrum users to gain access

[62] *See* 47 C F R § 2 1091 and 2 1093

[63] *See generally Rural NPRM* at 7, para 10

to licensed spectrum by entering into spectrum leasing arrangements on reasonable market-driven terms between the private parties Specifically, we adopted rules to remove regulatory uncertainty and establish clear policies and rules concerning leasing arrangements. In many Wireless Radio Services, licensees are now free to enter into voluntary leasing transactions with spectrum users seeking access to a licensee's spectrum.[64] While the flexible framework facilitating spectrum leasing arrangements does not impose any special technical requirements or constraints on such transactions, in some cases these arrangements may be made easier through the use of emerging technologies like cognitive radio. As discussed in our *Secondary Markets Order*, the ability of potential spectrum lessees to identify available leasing opportunities and negotiate with licensees, *e g., access mechanism*, is important for successful secondary market transactions.[65] Also, mechanisms to ensure that licensees can reclaim their spectrum from spectrum lessees, *e g , reversion mechanisms*, are an important consideration for many licensees. The *Further Notice* portion of the *Secondary Markets Order* seeks comment on changes needed in licensing policies or in the provision of licensing information to facilitate development of such a secondary marketplace in spectrum. The *Further Notice* also acknowledged the Commission's plans to conduct a separate proceeding on cognitive radio that might, *inter alia*, address the issue of technical requirements for possible leasing of public safety spectrum.

49. A cognitive radio could incorporate mechanisms that would enable voluntary spectrum leasing transactions between licensees and potential lessees that would not otherwise be possible without such technology Such leasing is currently permitted for a significant number of non-public safety Wireless Radio Service licensees, but subject to potentially prohibitive transaction costs. Cognitive radio technology could possibly drive transaction costs to a lower level by automating some or all of the process of negotiating the terms of a lease A lease could specify the frequencies available, power levels, locations where the spectrum could be used and time limits on use, and the radio could ensure that the terms are met While we expect that these capabilities would typically be used in the context of a prior leasing arrangement between the parties involved, cognitive radio technology could eventually allow licensees and potential lessees to negotiate for leased spectrum use on an *ad hoc* or real-time basis,[66] without the need for prior leasing agreements with all potential lessees (subject, of course, to whatever requirements the Commission has imposed on the nature and/or filing process for spectrum leases)

50 Licensees and potential lessees could exchange information via a communication link identifying the spectrum that would be leased as well as the then current terms and conditions for its use. The licensee could, in this manner, control access to and keep track of third party use of leased spectrum by, for example, an exchange of "tokens" sent to the lessee's devices.[67] Security of such transactions can

[64] *Secondary Markets R&O/FNPRM* at 37, para 84.

[65] *See generally id* at 84, paras 221-23

[66] Academic literature has also described real-time secondary markets as "spot markets" in spectrum *See generally* J M Peha and S Panichpapiboon, "Real-Time Secondary Markets for Spectrum," *Proc 31st Telecommunications Policy Research Conference (TPRC)*, Sept 2003

[67] Token approaches rely on the encrypted exchange of unique information used to verify a user's identity when opening and maintaining a secure communications exchange Tokens would provide a means of ensuring lessees would only transmit on available frequencies when they receive an electronic token authorizing them to do so These tokens would among other things enforce terms such as the specific period of time allowed, thus providing PS licensees a high confidence that lessees will vacate the spectrum when the lease expires Such technology is used in other resource allocation problems, such as in enforcement of software license terms PKI applications facilitate the authentication and exchange of information needed for the encryption of secure communications (continued)

be reinforced using technologies like the modern Public Key Infrastructure (PKI) mechanisms used widely by industry today. We seek comment on technical methods that might be used to provide information necessary for leasing and how a device would "enforce" the terms of the lease Although the Commission may not need to adopt specific technical requirements for these mechanisms, we seek comment on whether the Commission could reduce uncertainties that may inhibit leasing transactions by encouraging voluntary technical standards for access to a licensee's spectrum. What approaches to facilitating spectrum leasing transactions could best achieve the goals of our flexible and market-driven policies for spectrum leasing?

2. Interruptible Spectrum Leasing

a) Background

51 As described above, secondary market arrangements encompass a wide variety of transactions We expect that many licensees will enter into leasing arrangements under which they retain only minimal rights to access the spectrum for their own use during the term of the lease Other licensees, however, may wish to condition leased use of their spectrum on retaining the right to "interrupt" or preempt a lessee's use temporarily in order to satisfy their particular operational requirements for immediate access, reliability, or security. For instance, a licensee may have a critical need to access substantial amounts of spectrum, but only very infrequently and for limited time periods Such a licensee may well be very interested in leasing its unused spectrum, but only if it can assure that its critical needs will continue to be satisfied. Cognitive radio technologies would appear to make interruptible leasing practical for the first time, and thus open new opportunities for licensees to make their spectrum available to third parties on a voluntary basis. We would anticipate that interruptible spectrum leasing would be particularly relevant to possible leasing by public safety licensees, whose responsibilities and spectrum usage requirements are likely to demand robust technical mechanisms to ensure interruptible spectrum leasing

52. By way of background, the Commission provides state and local jurisdictions with dedicated spectrum to carry out their public safety obligations. Pursuant to Part 90 of our rules, the Commission licenses and regulates non-federal[68] radio communications of state and local governmental entities and certain other categories of activities [69] Communications transmitted over public safety facilities may include, for example, communications among members of a firefighting team, directions to an ambulance crew, or coordination among different police and fire agencies responding to a regional crisis. The activities supported by public safety communications systems rely heavily on the immediate, reliable and secure use of spectrum, particularly when safety of life is involved. Public safety activities and their associated communications needs are by their very nature highly time-critical, and characterized

(Continued from previous page)
Cognitive radio technologies could facilitate negotiation capabilities through the use of such techniques We discuss the encryption techniques involved in greater detail in *infra note* 76

[68] The Commission's statutory authority limits its jurisdiction to the regulation of non-federal entities Use of spectrum by federal entities is managed by the National Telecommunications and Information Administration (NTIA)

[69] *See* 47 C F R § 90 15 (medical services, rescue organizations, veterinarians, persons with disabilities, disaster relief organizations, school buses, beach patrols, establishments in isolated places, communications standby facilities, and emergency repair of public communications facilities)

by the very high peak-to-average use ratios with low average use, discussed above [70] Given these constraints, the feasibility of leased use of public safety spectrum during periods of low usage may depend heavily on the availability of technology to ensure that public safety entities would regain immediate access to their spectrum when needed for emergency use. Cognitive radio technology can provide the technical mechanisms to ensure the leased spectrum is instantly and reliably available for public safety use during emergencies serve a critical role in making leased use of public safety spectrum possible

53 In the Further Notice portion of the Secondary Markets Order, we sought comment on whether to permit public safety licensees to lease their licensed spectrum to other entities.[71] We noted that allowing public safety licensees to lease their spectrum had the potential to bring a variety of public interest benefits including: more efficient use of public safety spectrum, providing an avenue for multiple public safety entities to use the same spectrum, and providing financial resources to public safety licensees [72] We also recognized that public safety licensees who chose to enter into leasing arrangements would need near-instant access to their full spectrum capacity during emergencies We noted that while public safety entities have traditionally used technology that required assignment of full-time dedicated spectrum, new technologies might allow reliable near-instant access by public safety licensees during emergency periods, yet still permit use by lessees at times of low public safety demand. We stated our intention to begin a proceeding on cognitive radio technologies that would address this topic.[73] While the issue of public safety leasing remains pending in the Secondary Markets proceeding, we seek comment below on possible approaches for use of cognitive radio to enhance the efficient leased use of public safety spectrum.

b) Discussion

54. In this item, we seek comment on potential mechanisms for lessees to access spectrum by means of cognitive radio technology that would provide licensees with the ability to rapidly regain the use of the spectrum when needed Technology that provides licensees with highly reliable and near-instant access to leased spectrum could be beneficial to a wide variety of spectrum users, such as satellite, cellular, PCS and private radio network licensees, and we accordingly are seeking comment generally on what steps might facilitate the use of this technology For instance, specifying the technical methods of accessing and reclaiming spectrum could benefit both licensees and potential lessees by standardizing equipment designs, thus lowering equipment, and therefore transaction, costs. An important potential application of this framework is to possible public safety spectrum leasing, where access to, as well as reliable and secure use of, spectrum are critical and the public interest may require strong technical assurances Therefore, with respect to that particular application, we are seeking

[70] *See Spectrum Policy Task Force Report* at 43, Bykowsky, Mark M and Marcus, Michael J., "Facilitating Spectrum Management Reform via Callable/Interruptible Spectrum," 2002 Telecommunications Policy Research Conference (September 2002) at 15, available at http //intel si umich edu/tprc/papers/2002/147/SpectrumMgmtReform pdf (*Bykowsky/Marcus Report*); FCC Cognitive Radio Workshop, "Cognitive Radio Technologies in the Public Safety & Governmental Arenas," Presentation by Michael Marcus, Sc D, Office of Engineering and Technology, Federal Communications Commission, at 2, 12 (May 19, 2003) (*Marcus Cognitive Radio Workshop Presentation*).

[71] *See Secondary Markets R&O/FNPRM* at 103-104, para. 291-92

[72] *See Secondary Markets R&O/FNPRM* at 103-104, para 291-92

[73] *See generally id* at 87-88, para 232.

comment *inter alia* on whether, if we decide to permit public safety leasing,[74] we should identify one or more specific technical approaches in its rules to be employed by lessees, either at the discretion of the public safety licensee or on a mandatory basis under our rules

55 As described in detail below, we focus here on technical measures for ensuring return of spectrum to the primary licensee under pre-designated conditions. Cognitive radio technologies can be used both to identify spectrum that is available for leased use and to ensure that it reverts to the licensee under the prescribed conditions In particular, we set forth the details of a "beacon" approach that would ensure that licensees would retain real-time access to their leased spectrum. Of course, the beacon and other approaches described below are not necessarily the only ones that could facilitate leased access to spectrum while providing licensees with the ability to reclaim it quickly with ultra-high reliability We therefore seek comment on other methods that could achieve the same goals, and how these methods should be reflected in our rules

56. *Access/Reversion Mechanisms.* There are generally two categories of access/reversion mechanisms that could be used, those that rely on the overt permission of the licensee and others that sense the operating environment.[75] Each mechanism represents a somewhat different balance of reliability, security, cost, and complexity Among mechanisms relying on overt exchanges for permission, the least complex and possibly most economical to implement are mechanisms that would permit a lessee to transmit until the licensee signals the user to cease operations Reliability is limited under this approach because a lessee who is unable to receive the signal ordering it to cease operation may not properly relinquish use of the spectrum. "Handshaking" approaches would offer more reliability and security by requiring a lessee to request and receive explicit permission to use spectrum before each transmission, but this approach increases the complexity of implementation and the large number of interactions between the two parties may require the dedication of a separate "control" frequency Reversion mechanisms using sensing techniques have tradeoffs. "Listen before talk" mechanisms would permit a lessee to transmit whenever it did not detect a signal by the licensee on a given channel. This mechanism is fallible, however, because the licensee's signal may not be heard by the lessee under unfavorable propagation conditions

57. "Beacon" systems offer more in the way of the robust security and reliability features that are essential for interruptible spectrum leasing. In a beacon system, the lessee's transmitter must have the ability to receive a control signal sent continuously by the licensee at times when transmissions by the lessee are permitted. The lessee may not commence transmissions if the beacon signal is not received, and if the beacon signal is present but then stops while the lessee is transmitting, transmissions must cease within a specified time interval. The beacon could be an RF signal sent by the licensee on a designated control frequency, or it may be a signal received over a physical connection such as fiber, copper or coaxial cable If the beacon signal suffers from unfavorable propagation or the physical connection is lost and the beacon signal is not heard by a lessee, the licensee has "fail-safe" protection against interference, because if the lessee cannot hear the beacon signal, it must cease transmission

[74] As described in text, our consideration of interruptible spectrum leasing in this proceeding was contemplated at the time that the *Secondary Markets Further Notice* was adopted, and is in no way intended to prejudge our decision in that proceeding whether to permit leasing by public safety licensees

[75] *See generally* Comments of the Dandin Group, Docket 02-135, July 8, 2002, Comments of Prof Jon Peha, Docket 02-135, July 7, 2002

58 We seek particular comment on the beacon approach, which appears to provide the reliability necessary for some leasing arrangements, and can incorporate features needed for secure access, yet offers reasonable cost and acceptable complexity to implement and maintain. For example, applying this approach to a public safety leasing scenario, the public safety licensee would have control of the beacon and thus could directly regain control of the spectrum when needed. The beacon approach also allows a licensee to incorporate both access and reversion techniques into a technical solution, if it so desires The lessee's device would have to incorporate the capability to check for the beacon signal at prescribed intervals If the lessee's transmitter failed to receive a properly authenticated beacon signal for a prescribed time period, it would be programmed to assume access is no longer authorized and would cease use of the leased spectrum. The licensee would have the ability to reclaim the use of its spectrum after the prescribed listening period. In addition, the licensee's access, return, or reversion of its spectrum would not be impeded by unfavorable signal propagation because no explicit order to the lessee is necessary to terminate the lessee's use.

59. We also seek comment on how information about permissible leased uses of spectrum could be exchanged via a technical mechanism, such as a beacon signal, and on the cognitive capabilities that equipment used by a lessee must have, such as DFS, TPC and geo-location determination, to work with the chosen technical mechanism. For example, the negotiation of spectrum leasing opportunities would most likely require information about spectrum availability, *e g.*, which channels, scope of authorized service area, and the characteristics of the spectrum available, *e g.*, modulation, power limits. Other necessary information might include the amount of spectrum available, its expected duration, and perhaps its cost. Different technical information would be needed depending on the nature of the service, frequency bands employed, minimum acceptable quality of service requirements, and other characteristics of licensed and leased spectrum users We recognize that some of this information might be provided in the negotiation of a long-term leasing agreement However, cognitive radio technology could be designed to allow licensees to make this information available on a real-time basis and allow automated negotiation of the terms of leased access. In any case, any access mechanism would have to be consistent with the legal framework providing for secondary market transactions in spectrum that we adopt in our separate proceeding on secondary markets.

60 We seek comment on technical methods that might be used by a beacon approach, including those associated with a real-time automated negotiation of leased use rights In this regard, we describe below several specific technical proposals for a beacon mechanism and the equipment that could be used by the spectrum lessees As noted above, the beacon need not necessarily be in the form of an RF signal, but could be a physical connection like fiber, copper or coaxial cable and achieve the same results because the key factor of the beacon is the presence of the encrypted signal controlled by the licensee. First, under our proposal, the beacon signal would be sent either constantly or no less frequently than once per second so equipment used by lessees will be able to quickly detect the absence of an authorized beacon signal. Second, to protect against unauthorized use of spectrum, the beacon would contain information on the channel(s) available to prevent unauthorized use of channels by lessees. In addition, the beacon would include the time of day and an electronic signature to prevent "spoofing," whereby an unauthorized third-party originates a rogue beacon signal or retransmits an earlier beacon signal [76] The beacon's electronic signature should be sufficiently robust to make

[76] Two methods of encryption could facilitate this approach "Secret-key," or symmetric-key, encryption uses a single "private" key for both encryption and decryption that must be exchanged for users to securely communicate. "Public-key," or asymmetric-key encryption, used in PKI systems, uses two keys, a private key held locally, and a public key stored on a key server that used alone can enable secure communications. The public-key approach does not require the private key be exchanged, making it less susceptible to masquerading than the secret-key (continued .)

generating a rogue signal extremely difficult, *e g* , use 128-bit encryption, but we seek comment on what level of security would be needed to protect against unauthorized use. While we seek comment on the need for the Commission to define the technical requirements of beacon signatures in order to avoid possible harm from licensees using duplicitous signatures, we recognize that ongoing industry efforts towards standards, such as for public safety communications, might address such issues without need for regulatory oversight. We also seek comment whether multiple beacons should be required in the event that a licensee wishes to make multiple channels or frequency bands available to multiple lessees

61. Under such a beacon proposal, cognitive devices used by spectrum lessees could incorporate these and other technical safeguards to ensure that use of the spectrum by the licensee would not be compromised For example, devices would be capable of frequency agility to allow operation only on the channels or frequencies designated as available by the licensee and avoid operation on any other frequencies. We seek comment on other approaches that might be used to constrain leased use to authorized channels We thus seek comment on all of the proposals regarding access/reversion discussed above and on alternatives that may provide similar levels of reliability, security, and implementation complexity

62. *Public Safety Leasing* For the reasons summarized above, one particularly apt use of interruptible leasing would appear to be possible spectrum leasing by public safety entities. We anticipate that public safety licensees will seek to condition leased use on terms that preserve their unfettered right of access to the leased spectrum as appropriate to meet public safety needs. For these services, it may be in the public interest to ensure that access and reversion can be achieved reliably and in a manner secure against unauthorized use, yet without undue complexity and burdensome costs for implementers Furthermore, the public interest may also require that the provision of leased use of this licensed spectrum must not diminish the ability of these licensees to meet their public interest responsibilities Thus, we seek particular comment in the public safety context on the beacon proposal and the other access/reversion mechanisms discussed above. One potential approach would be to establish a technical model for reliable access to and secure reversion of leased spectrum that certain licensees would have the option of using to structure their leasing arrangements. Alternatively, the Commission could adopt the technical model in the form of minimum technical requirements for lessees of public safety spectrum Under either alternative, establishing technical criteria for cognitive radio devices to provide for access to and reversion of leased spectrum could help to achieve the significant benefits of spectrum leasing without detrimentally affecting public safety licensees' critical reliance on wireless communications. In any case, any technical rules that result from this proceeding with respect to leased use of public safety spectrum would be subject to the outcome of the *Secondary Markets* proceeding.

63 In addition to seeking comment on the application of technical access/reversion models to possible public safety leasing, we also seek comment here on particular technical issues that would appear to have particular relevance to possible public safety leasing. For example, would changes in modulation type or other parameters as opposed to a cessation of transmission be sufficient in the event a public safety licensee needs to reclaim spectrum? We also anticipate that transmitters operated on leased public safety frequencies would incorporate TPC so the public safety licensee could specify the appropriate operating power, and would be programmed to detect a properly authenticated public safety

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method However, public-key encryption involves more processing and therefore requires more processing power and time to send and receive data These methods are currently used to maintain the security of electronic mail and online transactions over the Internet and allow users to send messages or exchange confidential information that can not be viewed by unauthorized parties beacon within two seconds or cease use of the leased spectrum. We seek comment on these proposals, as well as on alternatives to the proposed signal and reversion times that could offer acceptable reversion capability to the public safety licensee Additionally, other cognitive radio technologies may offer alternative approaches to the proposed beacon approach. We seek comment on any alternatives that may also achieve our goals, *e g.*, reliability, security, rapid reversion, etc., for public safety spectrum leasing

64. The speed with which a public safety licensee can reclaim access to its licensed spectrum will be an important consideration in any reliable public safety reversion mechanism. In many instances, public safety use, for example, may not spike within a few seconds in response to emergencies but is more likely to grow at a rapid non-linear rate Under such usage, instantaneous reversion may be unnecessary, and an appropriate reversion return time may be identified We seek comment on whether and how cognitive radio technologies could be employed to permit the "tiering" of leased channels, which could make some channels available under a system with fast turnaround and other channels with slower turnaround. We also seek comment on public safety use and what appropriate minimums for time to return and at what rates are needed from usage patterns. We seek comment on whether beacon technology would best be implemented in multiple-channel trunked base stations; and whether one or more channels in such base stations could serve the beacon function. We also seek comment on how use of beacon-based technology could guard against interference when, on occasion, radios in a given system operate in the direct mode, *i e* a mobile or portable radio communicating directly with another mobile or portable radio without the signals going through the base station.

65 We also seek comment specifically on how the goals for public safety access to spectrum should be achieved, including any alternative features that proposed technical solutions should employ, and on other considerations important to addressing the technical aspects of public safety spectrum leasing transactions. In this regard, we recognize that although public safety licensees would want to retain control of any cognitive based technology used to ensure the reversion of leased spectrum, the acquisition of the technology may be funded by lessee(s), subject to the terms of a negotiated lease.

66 Although these specific issues may be of particular import to possible public safety leasing, we also seek comment on them in the context of interruptible leasing by licensees other than public safety entities

67 *Other Issues* We also seek comment on how to ensure that lessees of spectrum do not inadvertently transmit outside the licensee's authorized area and cause harm to other users In general, we assume that a beacon transmitting in a licensed public safety frequency band at the same power level normally used in the band would provide coverage over the public safety entity's licensed area. This should act as a safeguard against lessee operation beyond the licensed service area because the lessee's radio will not be able to receive the beacon beyond a certain distance. However, because the coverage area of a beacon may not precisely match the licensee's service area and could extend beyond the service area, it may be possible for a lessee to receive a beacon signal outside the authorized service area. We seek comment on whether there are technical mechanisms that could be used to ensure that lessees operate only within the geographic limitations of the license.

D. Other Applications of Cognitive Radio Technology

1. Dynamically Coordinated Spectrum Sharing

68. Cognitive radio devices' awareness of their environment and ability to use spectrum in response thereto offer new approaches as well as significant benefits for our existing procedures facilitating spectrum sharing. Many licensed services and their associated devices operate in the same frequency bands by coordinating their use to avoid mutual interference. Coordinated use enables more

users to use a given frequency band than would otherwise be possible without coordinated sharing Below we seek comment on the capability of cognitive radio technologies to encourage coordinated spectrum sharing under existing and new regulatory frameworks

69 *Coordination of Licensed Operations* Under current policies, co-frequency spectrum sharing among licensed services is usually accomplished with formalized procedures. These "prior coordination" procedures generally require applicants and licensees to identity and address the interference potential of their proposed spectrum use with incumbent users in an engineering analysis performed prior to filing an application.[77] Typically these engineering analyses are based on "worst case" assumptions, even if the "worst case" occurs relatively infrequently. Prior coordination approaches are generally practical and spectrally efficient when sharing conditions do not change significantly over time Prior coordinated sharing in the C-Band between GSO FSS and terrestrial fixed services (FS) did not result in significant underutilized spectrum because early GSO earth stations operated with a limited number of transponders on a single satellite and both the earth station and the FS facilities' directionality remained constant. Today GSO earth stations are usually coordinated for more than one satellite orbit position and transponder configuration, often called "full-band, full-arc" to support business models that supply satellite capacity on demand, such as with "teleport" providers, and also ensure systems can rapidly respond to satellite failures without interference.[78] Such coordination scenarios may offer opportunities for dynamically coordinated spectrum reuse.

70. Informal *ad hoc* sharing mechanisms are often used in frequency bands with different services that have unpredictable spectrum use patterns. Typically, informal sharing mechanisms rely on local frequency coordinators to manually track frequency use in a given geographic area and inform parties of frequencies currently not in use Coordination potentially could be made more effective with real-time information gathering and automated waveform selection made possible by cognitive radio technologies

71 The benefits that could be gained by relying on cognitive technology to facilitate real-time spectrum coordination could become very significant as more and varied services share spectrum. Our rules often require that new services sharing spectrum with incumbent operations coordinate proposed spectrum use with existing operations. In many cases, our rules provide a framework for sharing, such as between non-geostationary orbit (NGSO) FSS and fixed/mobile operations.[79] NGSO

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[77] *See generally* 47 C F R §101.103 While the rules in Section 101 103 apply to the fixed service, other terrestrial services have adopted this general approach either through duplication of the procedures or direct reference to that section For BAS, Section 74 638(b) incorporates by reference the coordination procedures in Section 101 103(d) For CARS, Section 78 36 describes the same, rather than incorporate by reference, the coordination procedures in Section 101 103(d) Likewise, similar rules govern the prior coordination of satellite earth stations. *See* 47 C.F R §§ 25.203, 25 251 Frequency coordination is also required in the Private Land Mobile Radio Services (PLMRS) *See* 47 C.F R § 90 175

[78] While such spot-markets in satellite capacity were not envisioned in the 1960's when our coordination approaches were first devised, today providers of satellite capacity provide such connectivity even on minute by minute basis, across various bands, and through numerous satellites

[79] For example, the 1990 proceeding allocating spectrum for FSS feeder links in the 27 5-29.5 GHz first presented the instant issue of terrestrial and satellite sharing In that proceeding we considered the feasibility of FSS feeder link earth stations providing backbone services for Iridium coordinating with existing and terrestrial services such as the LMDS services *See Rulemaking to Amend Parts 1, 2, 21, and 25 of the commission's Rules to Redesignate the 27 5-29 5 GHz Frequency Band, to Reallocate the 29 5-30 0 GHz Frequency Band, to Establish Rules and Policies for Local Multipoint Distribution Service and for Fixed Satellite Service*, CC Docket No. 92-297, *First* (continued)

FSS satellites move across the sky, requiring that an earth station track and utilize multiple satellites to maintain continuity of service. As a result, particular frequencies are effectively unused in directions other than the instantaneous direction in which an earth station is pointed. Using commercially available software tools, information about the satellite system and its orbit parameters, sensed information about the RF environment, or direct information about the satellite system, the direction of the earth stations' transmission or reception could be identified, allowing some users to share frequencies in directions that could be identified for coordinated use

72. Various cognitive techniques could be used to facilitate coordination and increase spectrum reuse by performing necessary engineering analysis and other frequency coordination tasks in near real-time. We note that our existing framework, and industry practices, for NGSO FSS sharing rely on such dynamic coordination techniques.[80] For example, such tools and technologies could be used to perform engineering analysis to identify desired to undesired signal ratios for terrestrial and satellite links, because satellite orbit parameters, desired time period, and locations of terrestrial links and earth station are known or calculable The actual occurrence of "worst case" interference conditions could be anticipated and avoided by changing terrestrial paths, changing satellite uplink or downlink paths, modifying RF parameters, or through other techniques. Using cognitive radio technology, one could have FS links in areas that would otherwise not be available under static coordination procedures (such as within certain distances of FSS earth stations). For example, terrestrial operations that occasionally operate near NGSO earth stations could potentially improve their spectral access by agreeing to employ technologies that would anticipate interference and modify or cease operations on a given path and reroute traffic via different paths (using known poly-grid approaches) to prevent that interference.[81] Alternatively, predicted interference could be avoided if the NGSO satellite earth station could change or "hand-off" to a different satellite when the NGSO signal path was approaching that of the terrestrial fixed

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Report and Order and Fourth Notice of Proposed Rulemaking, FCC 96-311 at 11-12, para 27 (rel. July 22, 1996) The Commission has also allocated NGSO FSS spectrum in the Ku-band where NGSO FSS uplink and downlink operations coordinate with existing terrestrial *See generally Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range,* FCC 00-418, *First Report and Order and Further Notice of Proposed Rule Making,* ET Docket No 98-206, 16 FCC Rcd 4096 (rel Dec 8, 2000) (*NGSO FSS R&O*) NGSO FSS downlink operations share with FS operations in the 10 7-11 7 GHz band, and NGSO FSS downlink operations share with BAS and CARS operations in most parts of the 12 75-13 25 GHz band *Id*

[80] To prevent interference when satellites from two NGSO FSS satellite systems align above an earth station, such systems potentially rely on at least three cognitive capabilities When such an alignment is detected or predicted by an NGSO system, the system can avoid interference by using different frequencies, alternative satellites in their respective systems. or alternative polarizations *See* ITU-R S 1431, *In the matter of the Establishment of Policies and Service Rules for the Non-Geostationary Satellite Orbit, Fixed Satellite Service in the Ku Band,* IB Docket No 01-96, *Report and Order and Further Notice of Proposed Rulemaking*, FCC 02-123, 17 FCC Rcd 7841, 7857, para 53 (2002)

[81] Polygrid, or mesh, networks emphasize the use of multiple nodes to create a large number of possible paths to connect two or more endpoints The multiple connectivity of such networks allow endpoints to be connected even when some individual links have to be turned off to prevent interference to or from NGSO satellite systems *See generally* Harry G Barker III , David A Calabrese, David A Garbin, J Edward Knepley, Dr Martin J Fischer, and Dr Gregor W. Swinsky, The Circuit Switched Network Design and Analysis Model. A Chronology of Its Development and Use, published in the 2000 The Telecommunications Review (discussing defense applications of polygrid routing features in wireline networks), *available at* http / www mitretek org/pubs/telecom/review00/article8 doc

system Thus, by adding cognitive radio capabilities in the terrestrial or satellite systems, or both, it can become possible to increase spectrum sharing beyond what it is otherwise possible. Furthermore, cognitive capabilities could improve sharing among terrestrial users as well

73 We seek comment on ways that we may encourage the use of dynamic coordination approaches For example, what incentives or regulatory frameworks for dynamic coordination approaches might facilitate satellite and terrestrial coordinated sharing. What coordination procedures would be appropriate for terrestrial to terrestrial sharing? Could satellite providers employ a spectrum reversion mechanism discussed above to permit real-time coordinated use without unreasonable risk of interference to their operations? Would financial incentives encouraging dynamic coordination approaches be warranted? Could our secondary market spectrum leasing provide a framework for such financial incentives? Would explicitly making dynamic coordination an option in our existing coordination procedures be in the public interest?

2. Facilitating Interoperability between Communication Systems

74 An important focus of the Commission has been the facilitation of interoperability among non-federal public safety entities Cognitive radio technologies offer urgently needed solutions to the increasingly crucial interoperability demands facing first-responders and other licensed users.[82] The Act and our rules currently provide a regulatory framework for interoperability.[83] This framework includes various Commission efforts to facilitate interoperability between non-federal entities at the national, regional, state-wide and local level.[84] Also of importance is interoperability between non-

[82] Wide agreement exists among expert commissions, official reports and other documents on the critical need to provide first responder and emergency management agencies at the Federal, State and local levels with interoperable communications systems to enable them to coordinate response and recovery efforts. *See e.g,* Intergovernmental Dimensions of Domestic Preparedness, Harvard Executive Session Memorandum, Appendix H, Third Annual Report to the President and the Congress of the Advisory Panel to Assess Domestic Response Capabilities for Terrorism Involving Weapons of Mass Destruction, A National Action Plan for Safety and Security in America's Cities, The United States Conference of Mayors, December 2001, Institute for Security Technology Studies at Dartmouth College, The First Line of Defense Tools and Technology Needs of America's First Responders in the Aftermath of September 11, 2001, available at http //www.ists.dartmouth edu/iria/fld/fld_draft pdf

[83] Section 154(o) states "[f]or the purpose of obtaining maximum effectiveness from the use of radio and wire communications in connection with safety of life and property, the commission shall investigate and study all phases of the problem and the best methods of obtaining the cooperation and coordination of these systems." 47 U S C § 154(o), *see also* 47 U S C § 151 Interoperability among public safety systems is defined in Section 90.7 of our rules as "[a]n essential communication link within public safety and public service wireless communications systems which permits units from two or more different entities to interact with one another and to exchange information according to a prescribed method in order to achieve predictable results " 47 C.F R. § 90 7. Our rules currently provide for interoperability in some bands and define standards for such communications *See e g* 47 C F R § 90 547 (requiring mobile and portable transmitters operating in 764-776 & 794-806 MHz be capable of operating on all designated nationwide narrowband interoperability channels); 47 C.F R § 90 548 (defining technical standards for narrowband interoperability channels), 47 C.F.R § 90 549 (requiring transmitters operating in 764-776 & 794-806 MHz bands be certified as required by general technical requirements for Part 90)

[84] The frequencies include 2 6 MHz of the 700 MHz band, 5 channels in the 800 MHz band, 5 channels in the 150 MHz band (VHF band), and 4 channels in the 450 MHz band (UHF band) Among these frequencies, five channels are designated for nationwide interoperability communications Regional planning committees address a variety of interoperability frequency planning at the regional level. Under this framework States administer (continued)

federal public safety entities and federal government first responders. For instance, the Commission has provided for federal government entities' use of 700 MHz public safety spectrum when used for interoperable communications.[85] In addition, non-federal public safety entities sometimes use frequencies allocated to federal government use[86] The Commission has continued to broaden this framework in the context of other proceedings by designating new spectrum for public safety interoperable use, for instance in the DTV transition where 2.6 MHz of the 24 MHz of added spectrum is reserved for public safety interoperable use.[87] Despite these efforts, lack of interoperability has been identified as a significant problem in the response to several disasters involving multiple jurisdictions, such as the September 11, 2001, attack on the Pentagon and the 1982 Air Florida crash.[88] Cognitive radio technologies addressed in this proceeding offer a new means of reducing risks to safety of life and national security by increasing the opportunities for first responders interoperability.

75. Both industry and government bodies are actively addressing the complex issues posed by the need for interoperable communication between public safety entities. The Public Safety National Coordination Committee (NCC) recently made recommendations on interoperability and other related issues in their report to the Commission[89] The Commission's Office of Homeland Security is also exploring potential changes to the Commission's technical rules, policies, procedures, or practices that would facilitate development of cognitive radio technology to enhance public safety communications.[90]

76 Cognitive radio devices' capability to automatically or with some user input identify systems and users that need bridging, could facilitate interoperability under our existing regulatory framework. Devices capable of sensing and identifying signals could dynamically respond to new

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interoperable spectrum on the state level. 47 CFR § 90 525(a) ("States are responsible for administration of the Interoperability channels in the 764-776 MHz and 794-806 MHz frequency bands ")

[85] *See e g* 47 C F R § 2 103(b)

[86] For instance, non-federal responders from Montgomery County, Maryland Fire & Rescue; Prince William county, Virginia, Fire & Rescue, Virginia State Police, Virginia Department of Transportation; and numerous federal responders including the F B I and U S Park Police Public operate across the entire span of the 138-174 MHz band. *See* Public Safety Wireless Network Program, Answering the Call Communications Lessons Learned from the Pentagon Attack at 7-8 Table I and Map I (January 2002), available at http //www pswn gov/admin/librarydocs7/Answering_the_Call_Pentagon_Attack pdf (summarizing communication systems used by jurisdictions responding to Pentagon attack)

[87] *See generally The Development of Operational, Technical and Spectrum Requirements for Meeting Federal, State and Local Public Safety Agency Communication Requirements through the Year 2010*, WT Docket No 96-86, *First Report and Order and Third Notice of Proposed Rulemaking*, 14 FCC Rcd 152 (1998)

[88] Interoperability was a serious concern in the response to the terrorist attack on the Pentagon *See* Federal Emergency Management Agency, Managing the Emergency Consequences of Terrorist Incidents, INTERIM PLANNING GUIDE FOR STATE AND LOCAL GOVERNMENTS 25 n.9 (July 2002), available at http //www fema gov/pdf/onp/managingemerconseq.pdf. Interoperability was also a serious problem for first responders to the crash of Air Florida flight 90 in 1982 that resulted in 78 deaths under the 14th street bridge just miles from the Pentagon

[89] *See* Letter from Kathleen M H. Wallman to Michael Powell, Chairman, Federal Communications Commission, WT Docket No 96-86 (July 25, 2003) [hereinafter NCC *ex parte*]

[90] FCC Homeland Security Action Plan (July 10, 2003), *available at* http //hraunfoss.fcc gov/edocs_public/attachmatch/DOC-236428A2 doc.

jurisdictions seeking to deploy interoperable systems. Devices could, in real time, adapt waveforms received from one system and change their modulation formats (such as APCO25 to FM) and frequencies and facilitate interoperability with other systems. For example, during their response to the Pentagon attack, Arlington County Fire's ability to communicate with firemen reporting from other jurisdiction would not have been limited to their supply of radios to distribute. A device could simply have bridged communications from any jurisdictions arriving with their own radios Cognitive radio devices could also be used to connect to password protected databases available for public safety use that could help identify the kinds of frequencies and waveforms that dynamic interoperability would need to bridge.[91] Devices could also perform this interoperability bridging using encryption technology when secure communications are required.[92] Such a feature might be very useful for federal entities utilizing secure communications systems that assume responsibility for coordinating rescue and response efforts. FBI entities who assume control of coordinating such efforts may need to bridge from secure communication systems in order to communicate with certain non-federal entities. Cognitive radios may also contribute to the provision of E911 by providing a bridge between systems using different air interfaces to provide wireless E911 services We seek comment on how cognitive radio technologies can facilitate interoperability between systems We also seek comment on any rule changes necessary to take advantage of these benefits for interoperability between systems.[93] We also seek comment on how cognitive radio technologies can provide support to wireless E911 services.

3. Mesh Networks

77 Emerging technologies, such as "mesh" networks, rely on each node in an RF network to collect and disseminate information and optimize spectrum use by relaying messages through the RF network [94] We seek comment on the application of this technology and possible rule changes needed to facilitate the use of these technologies

78 In a mesh network, each transmitter interacts on a peer-to-peer basis with other nearby transmitters, while also sending and receiving messages mimicking a router that relays messages to and from neighboring transmitters. Through this relaying process, a message can be routed through other transmitters to its destination based on the current conditions of the network The received power at an antenna is reduced as the distance from a transmitter increases, and thus more power is required to transmit to a receiver farther away. Mesh networks function by "whispering" at low power to a neighbor rather than "yelling" at a high-power to a node far away. This approach may be spectrally more efficient

[91] To date, the Commission has declined to require the use of a password protected pre-coordination data base in the regional planning process. *See* The Development Of Operational, Technical and Spectrum Requirements for Meeting Federal, State and Local Public Safety Agency Communication Requirements Through the Year 2010, WT Docket No 96-86, *Fourth Memorandum Opinion and Order*, 17 FCC Rcd 4736, 4737 (2002) However, the NCC urges the Commission to review this decision and mandate its use *See NCC ex parte* at 6

[92] Our rules currently permit encrypted communication on all but two national channels reserved for interoperability *See* 47 C F R § 90 533(a)

[93] The NCC recommended that the Commission amend Section 90 of its Rules to include a new section titled "Interoperability Channels Administration, Use, Limitations" that would consolidate existing rules governing interoperability and any new rules that the Commission may adopt in response to the NCC's recommendations *See NCC ex parte* at 6

[94] *See* FCC Tutorial, Wireless Ad Hoc Mesh Network Technology, DA 02-1201, *Public Notice* (rel May 20, 2002)

than simply transmitting directly to a desired receiver at some distance and provide for better sharing scenarios We seek comment how such techniques could be applied to facilitate our goals of improved spectrum sharing

79. Mesh networks can allow radio use to expand to areas beyond the reach of network base stations, yet enable multiple users to avoid interference to each other This capability could make it possible to deploy operations in areas where line of site is obstructed or unavailable and the propagation characteristics of the band would otherwise require unobstructed line of site. For example, such a capability could be helpful for both licensed and unlicensed operations in the microwave bands where common obstructions such as trees limit the ability to deploy services with low power We seek comment how this technology might serve our efforts to facilitate broadband communication services to consumers, and any rule changes that might be necessary. We also seek comment on the impact that mesh networks will have on the aggregate interference to licensed services.

80 The ability of mesh networks to "self-heal" by responding to failures in the network may offer important benefits for ensuring network reliability. If one link in a mesh network fails, a message can be routed to its destination through alternate links. In this way all transmissions from the nodes of a mesh network operate in coordinated manner, in the same manner that Internet routers intelligently respond to outages by routing traffic around failures. We seek comment on how such capabilities could improve the reliability of wireless operations

E. SDR and Cognitive Radio Equipment Authorization Rule Changes

1. Background

81. Most radio transmitters are required to be certified before they can be marketed within the United States and Part 2 of the FCC rules specifies the procedures for obtaining certification for both licensed and unlicensed transmitters.[95] The certification rules require that the equipment be tested to show compliance with the applicable technical rules, and that an application, test report and certain exhibits be filed with either the Commission or a designated Telecommunication Certification Body (TCB)[96] The rules also provide that when any changes are made to the operating frequency range, modulation type or maximum output power of an approved device the manufacturer must file a new application for certification.[97] The rules permit certain changes to an approved device to be made though a "permissive change" procedure The permissive change rules require manufacturers to submit either a streamlined filing or no filing and do not require manufacturers to place a new identification number on a device[98]

[95] *See* 47 C.F R Part 2, subpart J.

[96] *See* 47 C F.R §§ 2 1033 and 2 960

[97] *See* 47 C F R § 2 1043(a)

[98] *See* 47 C F R § 2 1043(b) There are three classes of permissive changes. A Class I permissive change includes minor modifications to a device that do not degrade the characteristics measured at the time of certification. No filing is required for a Class I change A Class II permissive change includes modifications to a device that degrade the characteristics measured at the time of certification, although the device must continue to comply with the applicable rules Manufacturers must supply information on the Class II changes to the Commission or TCB and must receive an acknowledgement from the Commission or TCB that the changes are acceptable before the modified equipment may be marketed A Class III permissive change includes modifications to the software in a (continued)

82. In 2001, the Commission adopted changes to the equipment authorization rules to accommodate the developing software defined radio (SDR) technology[99] The Commission defined a software defined radio as a transmitter in which the operating parameters of frequency range, modulation type or maximum output power (either radiated or conducted) can be altered by making a change in software that controls the operation of the device without making any changes in the hardware components that affect the radio frequency emissions.[100] Although this broad definition covers both radios that have software imbedded on chips when the software can not be readily changed by the user as well as radios that are designed so the software can be easily changed after manufacture, the primary focus of this item is on the latter category. Possible ways to load new software into a radio after manufacture include over the air, through a connection to a personal computer or other programming device, and by replacement of a card or chip

83 The SDR rules were intended to make possible for manufacturers to obtain approval for changes to the operating parameters of a radio resulting from software changes without the need to physically re-label a device with a new FCC identification number in the field. The Commission made the rules permissive, rather than mandatory, thereby permitting a manufacturer the option to his declare a device an SDR at the time of filing for certification, but not requiring the manufacturer to do so. The Commission adopted the following rule changes for SDRs:

- Established a new streamlined procedure for obtaining approval for changes to the operating parameters of SDRs that result from changing the software in the device[101] The same FCC identification number may be used when changes are made to an approved device.
- Allowed a device's FCC identification number to be displayed electronically, rather than on a physical label.[102]
- Required SDRs to incorporate security features to ensure that only software that is part of an approved hardware/software combination can be loaded into an SDR. The exact methods are left to the manufacturer[103]
- Required manufacturers to supply a copy of the software that controls the operating parameters of a radio to the Commission upon request.[104]

84 Although the SDR rules were adopted over two years ago, to date no manufacturers have filed applications to certify a device under our new SDR rules. However, devices have been certified that

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software defined radio that change the frequency, modulation type, output power or maximum field strength outside the parameters previously approved Manufacturers must submit a description of the Class III changes and test results showing that the equipment complies with the applicable rules with the new software loaded to the Commission and must receive an acknowledgement that the changes are acceptable before the modified equipment may be marketed TCBs are currently not permitted to certify SDRs

[99] *See First Report and Order* in ET Docket No 00-47, 16 FCC Rcd 17373 (2001)

[100] *See* 47 C F R § 2 1

[101] *See* 47 C F R § 2 1043(b)(3).

[102] *See* 47 C F R § 2 925(e)

[103] *See* 47 C F R § 2 932(e)

[104] *See* 47 C F R § 2 944