THE POTENTIAL VALUE OF DECENTRALIZED TRUNKING AS REGULATORY PRECEDENT FOR THE INTRODUCTION OF DYNAMIC SPECTRUM ACCESS TECHNOLOGY

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Abstract— **One important way of obtaining the necessary regulatory permissions for Dynamic Spectrum Access ("DSA") technologies from domestic government agencies and the international spectrum management community is to demonstrate that there are policy and legal precedents for their introduction. A recent precedent centers on efforts in the U.S. to allow Unlicensed National Information Infrastructure devices to operate in the 5.25-5.35 GHz and 5.47-5.725 GHz bands without causing interference to existing radio frequency operations (government radars) through the use of Dynamic Frequency Selection ("DFS") and Transmit Power Control ("TPC"). Another, slightly older precedent is the U.S. Federal Communications Commission's policies and rules that permit the utilization of "decentralized trunking" in the VHF and UHF Private Land Mobile Radio ("PLMR") service bands. Under these rules, adequate "monitoring" (a.k.a., "listen-before-talk" or "LBT") is required in order to share spectrum under a decentralized trunking approach. This paper analyzes the potential value of this older precedent in advocating for broader regulatory acquiescence and near-term deployment of DSA technology.**

Arguably, in the U.S., a DSA radio system using technology to achieve decentralized trunking capabilities could be introduced onto shared channels in the PLMR bands without any major changes in the Commission's existing rules or policies. Using LBT functionality with advanced sensing algorithms, together with DFS and TPC capabilities, could promote shared access via decentralized trunking in the VHF PLMR band, where licensees often employ non-standard channel pairs or un-paired (simplex) channels, and the UHF PLMR band, which is often characterized as overcrowded but underutilized.

However, some economic and regulatory barriers to the development of robust secondary market access to these spectrum bands may hinder the full potential of DSA technologies in these bands.

Index Terms— **spectrum regulation, land mobile radio, trunking dynamic spectrum access, spectrum sharing, listen-before-talk, DARPA XG.**

I. INTRODUCTION

Successful development and deployment of Dynamic Spectrum Access ("DSA") technology will result in much more efficient use of increasingly scarce radio frequency ("RF") spectrum resources. Because of restrictive and often overly conservative government regulations restricting the use of and access to spectrum and because of past technological constraints, much of the radio frequencies that have been allocated and assigned by regulators often lay fallow despite increasing demand for access and bandwidth. More specifically, the use of traditional, heavily regulated, "command and control" or "static" methods of "managing" these valuable resources has resulted in spectrum going unused in the frequency, time and space dimensions. This under-utilization in the face of increased demand is often further exacerbated by the use of conservative, "worst-case," interference models and assumptions of regulatory and industry stakeholders. As stated in the report by the Spectrum Policy Task Force ("SPTF") of the U.S. Federal Communications Commission ("FCC" or "Commission") [1]:

> *In many bands, spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential users to obtain such access.*

The resulting under-utilization and administratively induced scarcity has been verified by spectrum occupancy measurements made by Shared Spectrum Company ("SSC") and others [2], [3].

As the SPTF report recognized, substantial amounts of spectrum capacity could be freed up by more decentralized, dynamic and "opportunistic" approaches to regulating and accessing RF spectrum. These approaches would take advantage of advanced technologies that exploit, among other things, the increased processing power or "intelligence" that can now be economically deployed in end user and other devices at the edge of networks. SSC's successful prototype development supported by the NeXt Generation Program ("XG") of the U.S. Department of Defense's Defense ("DoD") Advanced Research Projects Agency's ("DARPA"), among other things, has resulted in technology capable of finding

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even momentarily unused spectrum in a particular geographic area through the use of an integrated highly sensitive monitoring receiver and cooperative groups of transceivers. (Results of recent XG field demonstrations conducted by SSC are summarized in [4].) Using complex sensing and networking algorithms, if no current usage is detected, transmission is allowed (with appropriate limits on transmitter power or other constraints). Similarly, if subsequent usage of the spectrum by incumbent users is detected, communications is immediately stopped and other available spectrum sought so that the communications can continue. While the foregoing description is highly simplified, in the language of traditional RF engineering, one can quickly draw a parallel to the well-established notion of "listen-before-talk" or "LBT," the basic procedure or protocol for avoiding interference by monitoring for current usage of a channel.

Notwithstanding some predictions that advanced cognitive radio is a long way off, advanced DSA technology, such as that developed by SSC, will be introduced this year and will show how these techniques can significantly improve access to radio spectrum. As set forth in [5], the regulatory momentum in the U.S. supporting "smart" radio technology (*i.e.,* software defined radio and cognitive radio), secondary markets and other initiatives is a positive sign. Still, early deployment in the U.S. is likely to require actions by the FCC and by the National Telecommunications and Information Administration ("NTIA") in the form of equipment or system approval, frequency assignments and, potentially, minor modifications or waivers to existing regulations. One important way of obtaining the necessary support and regulatory permissions from these agencies (and from the international spectrum management community as well) is to demonstrate that there are policy and legal precedents for their introduction or are otherwise consistent with existing rules.

One relevant and very recent precedent centers on the FCC's efforts, in cooperation with NTIA and DoD, to allow Unlicensed National Information Infrastructure ("U-NII") devices to operate in the 5.25-5.35 GHz and 5.47-5.725 GHz bands without causing interference to existing Federal government radar operations through the use of Dynamic Frequency Selection ("DFS") and Transmit Power Control ("TPC") [6], [7]. Another, somewhat older precedent is the Commission's policies and rules that promote spectral efficiency through the utilization of "decentralized trunking" in the VHF and UHF Private Land Mobile Radio ("PLMR") bands. The purpose of this paper is to analyze the potential value of the decentralized trunking precedent in advocating for broader regulatory acquiescence and near-term deployment of DSA technology.

The balance of this paper is divided into three additional sections. Section II provides background information on the technical and regulatory aspects of decentralized trunking; Section III analyzes the value, in terms of the policy and regulatory precedent, of decentralized trunking for the broader acceptance and early introduction of advanced DSA technology like that developed by SSC under DARPA's XG program. Section IV provides a short summary and statement of conclusions.

II. BACKGROUND

This section provides information on the technical and regulatory aspects of decentralized trunking. It is sub-divided into two parts: The first part outlines the basic advantages of trunking in the context of PLMR and describes three forms of trunking that have been recognized by the FCC and deployed by licensees: namely centralized, decentralized and hybrid trunking. The second part traces the somewhat complex policy and regulatory history of trunking, again in the context of PLMR.

A. Advantages of Trunking in the Context of PLMR

Trunking was first introduced into the PLMR services when the Commission allocated spectrum in the 800 and 900 MHz bands for land mobile use and designated hundreds of narrowband channels for internal, private use by public safety, industrial, business and land transportation entities. The adoption of these new allocations, along with the associated technical and service rules and initial licensing of individual PLMR stations, took place throughout the mid-1970s and 1980s [8], [9]. Dating back the previous 50 years before these actions, most PLMR operations, including Federal government stations authorized by NTIA, were licensed in various segments of the VHF band from 25 to 50 MHz and from 138 to 174 MHz and the lower UHF band from 450 to 470 MHz. Stations were used to provide private voice dispatch services, rather than interconnected public mobile telephone services.[1] Trunking, as described in more detail below, utilizes more spectrally efficient technology than traditional, or "conventional," PLMR systems that have been around – and still are – since the beginning of land mobile radio.

1) Conventional PLMR Systems

Before the advent of trunking (and still today in particular channels) licensees in the PLMR services are assigned individual channels and operated manually in the familiar Push-to-Talk, Release-to-Listen ("PTT/RTL") mode.[2] In some cases, multiple channels were assigned to an individual licensee but it was up to the dispatcher and field units to manually select the channel used for a particular communications session. Because some operators needed to communicate with only a few mobile units and because there was not sufficient spectrum to give each licensee its own

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[1] Dispatch communications is associated with two-way communications between and among a dispatcher and mobile units in the field and does not include access to the regular, public switched telephone network ("PSTN"). It typically involves a "command and control" structure where a high degree of coordination among units is required. Such services are used heavily by the public safety community and by businesses like tow truck and taxicab companies that must dispatch units operated away from the principle place of business. Traditionally these systems were private in nature; that is, they were not used to provide service to others on a third-party or common carrier basis. For a more complete discussion of dispatch services *see* D. Hatfield, "The Technology Basis for Wireless Communications," chapter in *The Emerging World of Wireless Communications*, Annual Review of the Institute for Information Studies, A Joint Program of Nortel and The Aspen Institute, published by the Institute for Information Studies, 1996.

[2] In actuality, in the higher PLMR bands, the channels assigned consisted of two frequencies – one on which to transmit and one on which to receive. The assignment of channels with paired frequencies allowed the use of repeaters and facilitated full-duplex operation.

channel, they were generally required to "share" their channels with other operators in the same geographic area (*i.e.*, no licensees were granted "exclusive" rights to such channels). In order to avoid harmful interference among users on a shared channel, the FCC's rules imply (and, to a certain extent, social norms dictated) the utilization of the rudimentary PTT/RTL "protocol" mentioned above.[3] Licensees were constrained to this mode of operation – assignment to one or only a handful of manually selected channels and the LBT mode of operation – largely due to technical limitations. In FCC and industry terminology these systems are referred to as "conventional" (as opposed to trunked) systems.

Dispatch systems in the VHF and UHF bands proved popular and, in the 1960s, the associated growth in the number of dispatch users was very rapid. However, these systems, which typically used high transmitter power and high antenna sites to achieve wide-area coverage, suffered from a number of limitations, including low spectral efficiency. As noted in [8], one aspect of this inefficiency can be understood by considering a collection of independent channels each occupied by one or more conventional single-channel systems of the type just described. At any given instant of time, some of the channels may be heavily used while some may be unused or lightly used because, for example, the peak usage of the different operators/licensees may not coincide. It is clear that aggregating a group of such separately licensed/owned channels together and giving the collective group of users access to all channels on an "as needed" basis would give them better service in terms of encountering a channel-busy condition. Or, in the alternative, for the same quality of service, it would allow a greater volume of calls to be handled on the group of channels. This technique of combining (or "pooling") channels, allowing users to temporarily draw from the pool to carry conversations on an as needed basis, is called trunking and the resulting improvements in spectral efficiency are easily predictable and readily observed.

2) Centralized Trunking

When the Commission started to consider allocating additional spectrum for PLMR services in 1968 in response to the rapid growth in mobile radio, it was very interested in encouraging the development and deployment of more spectrally efficient technologies/systems in the new bands. Fortunately, the technology had evolved in terms of allowing engineers to (1) design radios that could be quickly tuned to operate on any one of multitude of channels in a given band and (2) incorporate the digital logic and signaling subsystems necessary to permit automated trunking.[4] Thus, as noted above, the Commission allocated spectrum in 1975 for the provision of more spectrally efficient dispatch services using multi-channel trunked systems, but only in the 800 and 900 MHz bands.[5] Moreover, it made provision for the operation of these systems by large organizations on a private, internal-use basis and by third-party providers on a commercial, private carrier basis.[6]

The multi-channel trunked systems that manufacturers developed for use in the new 800 and 900 MHz PLMR bands utilized "centralized" trunking. In a centralized trunking system, information on the status of the pooled channels (*e.g.*, in-use or idle) is stored in a computer-like device or controller typically located at the base station transmitter or repeater site. In one popular trunking system architecture, a dedicated control channel is used to exchange signaling information between the controller at the central site and the mobile units. In this architecture, the mobile units continuously monitor the control channel when they are in the idle state. When a dispatch call is initiated by a mobile unit or dispatcher, a digital signaling message is sent by the unit to the central controller identifying the group to be contacted and requesting the assignment of a channel. The controller then identifies an idle channel in the pool and sends out a signaling message to the calling and called units instructing them to tune to the selected idle channel. The units that are not participating in the call continue to monitor the control channel. Once the calling and called units or group are assembled on the selected channel the conversation is begun. When the call is completed, signaling messages are again exchanged and the selected channel is returned to the pool and identified as being idle. While the foregoing description is highly simplified, it provides a basic notion of how a centralized trunking system operates.

[3] While the FCC's rules in 47 C.F.R. Part 90, Subpart N (Operating Requirements), do not explicitly mandate the use of an LBT protocol in PLMR bands, they generally require licensees of shared channels to "restrict all transmissions to the minimum practical transmission time," "employ an efficient operating procedure designed to maximize the utilization of the spectrum," and "take reasonable precautions to avoid causing harmful interference, [including] monitoring the transmitting frequency for communications in progress and such other measures as may be necessary to minimize the potential for causing interference." 47 C.F.R. § 90.403(c), (e) (2006).

In 2005, the Commission said, in support of adoption of a "contention-based protocol" requirement in the 3650-3700 MHz band, that "[o]ur experience in the shared PLMR frequencies shows that non-exclusive use of frequencies can work well in some circumstances from an interference management perspective. Shared use in PLMR frequencies also allows for effective and efficient use of the spectrum and enables providers with limited resources access to spectrum for nominal application and licensing fees." Federal Communications Commission, "Wireless Operations in the 3650-3700 MHz Band; Rules for Wireless Broadband Services in the 3650-3700 MHz Band," ET Docket No. 04-151, *Report and Order*, 20 FCC Rcd 6502, 6511 ¶ 26 (2005) (available: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-05-56A1.pdf), petitions for reconsideration pending. In this same context, the Commission described such PLMR LBT-based operations as the "simplest form" of contention based systems, comparing it to "[m]ore complex schemes . . . such as that used by unlicensed Wi-Fi devices (also know as IEEE 802.11) [which use] a contention-based protocol known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)." *Id.* at ¶ 57.

[4] Signaling in telecommunications refers, *inter alia*, to the exchange of information between a subscriber device (e.g., a mobile radio) and its associated network needed to connect, manage, or disconnect a call. It is distinct from the exchange of user information once the call is established.

[5] Although the rules governing trunked systems initially restricted the use of the channels for interconnected mobile telephony-types services, these restrictions were eventually removed.

[6] The providers of non-interconnected multi-channel trunked dispatch services now operate on a lightly regulated private carrier basis. Providers of interconnected multi-channel trunked services that operate on a commercial basis are referred to as Specialized Mobile Radio operators and are treated as Commercial Mobile Radio Service providers for regulatory purposes. *See* 47 C.F.R. Part 20 (2006).

3) *Decentralized Trunking*

Another form of trunking is referred to as "decentralized trunking." In a decentralized trunking systems, information on the status of the pooled channels is not stored on a centralized basis and no dedicated control channel is involved. Once again using a highly simplified description, the decentralized system operates as follows: The mobile and dispatcher radio units continuously scan or monitor all of the pooled channels in the system. When a dispatch call is initiated by a mobile unit or dispatcher, the unit immediately stops at the next idle channel in the pool. The radio unit initiating the call sends out a signaling message on the selected idle channel identifying the group to be contacted. The resulting signaling message is of sufficient duration that it is certain to be picked up by the remaining units that are continuously scanning all channels in the pool. The radio unit initiating the call waits on the channel. When the scanning radios encounter the signaling message on the selected channel they pause briefly to determine if the call is for them and, if not, they resume scanning. On the other hand, if the call is for them, they remain on the selected channel and with the calling and called units gathered on the selected channel, the conversation is begun. When the call is completed, a signaling message releasing the channel is sent and the gathered units then resume their scanning of all channels in the pool.

It is important to note that, in contrast to the centralized trunking architecture, in the decentralized architecture, the individual radio units at the edge of the network are responsible for determining – through monitoring – the busy or idle status of the pooled channels and no dedicated control channel is involved. In short, there is no centralized data base and associated control channel for accessing that data base. Both the centralized and decentralized arrangements, however, allow individual users or groups of users to dynamically share the pooled channels. By doing so, they engender increased spectral efficiency – handling more users in a given amount of spectrum – while protecting those same users from interference – *e.g.*, hearing or having their message disrupted by other conversations. It should be obvious that, in addition to the centralized and decentralized architectures just described, arrangements that include elements of both (*i.e.*, hybrid trunking) are also possible.

B. *Policy and Regulatory History of Trunking in PLMR*

As explained above, trunking was first introduced into the PLMR industry when the Commission allocated additional spectrum for the service in the mid-1970s. In allocating the additional spectrum in the 800 and 900 MHz bands, the Commission made explicit provisions for trunking in both private, internal use and private carrier operations. A number of manufacturers responded to this new business opportunity and developed trunking systems based upon the centralized architecture described earlier. Still, the Commission continued its quest to make operations in the PLMR bands more spectrally efficient through enabling advanced technologies and it turned its attention to the PLMR services in the VHF and UHF bands.

1) *Refarming Proceeding*

In 1991, the Commission, responding to continuing growth in spectrum demand, commenced an inquiry to explore options to promote more efficient and effective use of the PLMR bands below 470 [10]. In 1992, it sought comment on proposed regulations that would require the more efficient use of PLMR spectrum in the VHF and lower UHF bands [11]. This rulemaking proceeding, which became known informally as the "Refarming Proceeding," resulted in the consolidation of 20 discrete radio services, replacing them with two frequency pools – the Public Safety and the Industrial/Business Pools. The proceeding also led to the creation, over time, of additional channels for future communications needs. It did so by ordering a reduction in bandwidth of existing voice channels, initially from 25 kHz to 12.5 kHz, and ultimately to 6.25 kHz, or, equivalently, by requiring faster transmission rates within the existing channel bandwidths [12]-[15].

In addition to the two service categories, narrower channels and higher data rates, the Commission promulgated explicit rules governing centralized trunking in the VHF and UHF PLMR bands by adopting mechanisms to coordinate among shared licensees or convert shared channels into exclusive ones [13], [15]. In brief, the Commission sought to promote spectrum efficiency in these lower frequency bands by narrowing the channels and by encouraging the introduction of trunking which had proven so beneficial in the 800 and 900 MHz bands. However, the Commission faced an additional obstacle in developing explicit rules to govern the use of trunking in the VHF and UHF bands due to the fact that, unlike the situation in the 800 and 900 MHz bands, the existing channels in lower PLMR bands were, in many cases (especially in major urban areas), already heavily occupied by licensees or multiple operators using conventional systems on a shared basis using simple manual procedures or protocols.

Whereas the licensees of trunked systems in the 800 and 900 MHz bands had exclusive use of their channels in a particular geographic area, licensees of conventional systems in PLMR bands below 512 MHz often did not. This frequent lack of exclusivity created severe difficulties in terms of introducing centralized trunking in these lower PLMR bands. The first difficulty stemmed from the need in a centralized trunking system to set aside one assigned frequency for the dedicated control channel. Control channels, by their very nature, need to transmit continuously and, consequently, would cause interference to other intermittent users sharing the channel.

Even more fundamentally, in a centralized trunking system, a simple data base containing the current status of the pooled channels – busy or idle – is maintained in the centralized controller. The controller has no knowledge as to whether any given channel is being used by other independent licensees sharing that channel. Hence, if the controller does not maintain exclusive control over what access all users have to particular channels, it can inadvertently direct the radio units associated with a particular call to communicate on a channel that is already busy. This can cause severe interference to the non-trunked radios sharing the channel. Succinctly stated, the centralized trunked systems assume clear channels rather than channels shared with other systems on a non-cooperative basis.

Thus, in addressing these issues in the Refarming Proceeding, the FCC added a new Section 90.187 to its rules authorizing "trunking" in the bands between 150 and 512 MHz under certain conditions. Specifically, although the rules did not indicate differentiation among centralized and decentralized trunking, by their terms they seemed to be limited to centralized trunked systems because they required potential operators in these bands to have exclusive rights to use the associated channels or obtain the written consent from all other co-channel and adjacent channel licensees that would potentially be interfered with by using a trunked system.[7] The regulatory status of *decentralized* trunking using shared or non-exclusive channels was less clear.

Prior to the FCC's action in the Refarming Proceeding, neither centralized nor decentralized trunking was directly addressed in the rules governing the VHF and UHF PLMR bands. Some manufacturers and licensees had taken advantage of the lack of rules and apparently relied on previous Commission statements, deploying trunked systems using a decentralized architecture. As early as 1991, when it launched the Refarming Proceeding, the Commission stated that decentralized trunking in the lower PLMR bands that uses monitoring "is not prohibited" because it does not require exclusive channel assignments. At the same time, it sought comment on centralized and decentralized trunking and how to "differentiate between these types of dynamic frequency assignment" [10]. Seven years later, after Section 90.187 became effective without specific requirements for decentralized trunking, a coalition of FCC-designated Frequency Advisory Committees (or "frequency coordinators") raised concerns about PLMR operators' authority and ability to deploy decentralized and hybrid trunking systems in these bands [16].

2) 1998 Biennial Review Proceeding

The Commission addressed these concerns in its 1998 Biennial Regulatory Review proceeding and eventually adopted special rules governing the use of decentralized trunking in these bands [17]. Initially, the Commission suggested that new rules were not necessary since "[d]ecentralized trunking has always been permitted because the monitoring feature enables a decentralized trunked system to be used on shared frequencies" [18]. It believed "that Section 90.187 applies only to centralized trunked systems."

Later in the 1998 Biennial Regulatory Review proceeding, the Commission agreed that hybrid trunking systems (where at least one of the frequencies being trunked but not all the frequencies being trunked meet the original criteria specified in Section 90.187) allow operators, especially those located in spectrum congested areas, to make more efficient use of the spectrum. It therefore amended the rules to revise the definition of trunked systems to specifically authorize centralized, decentralized and hybrid systems in the PLMR bands between 150 MHz and 512 MHz.

As noted above, Section 90.187 originally required potential operators to have exclusive rights or obtain the written consent from all other co-channel and adjacent channel licensees that would be subject to predicted interference. However, such consent may be difficult to obtain because, in more densely populated urban areas (where the efficiency of trunking is needed the most) there may be a large number of potentially affected parties operating on both the same and adjacent channels and those parties – facing increased interference or the need to invest in new equipment to avoid such interference – have little incentive to give the required written consent.[8]

Because of the difficulties associated with introducing centralized trunking onto channels already occupied by conventional, shared systems, the Commission, in section 90.187(b) of its rules, provides for use of the LBT protocol (and hence decentralized trunking) in the VHF and UHF PLMR bands. Specifically, the referenced rule provides that:

> *Trunked systems operating under this section must employ equipment that prevents transmission on a trunked frequency if a signal from another system is present on that frequency. The level of monitoring must be sufficient to avoid causing harmful interference to other systems.*

Thus, in the proceeding adopting the current rules for these bands, the Commission made it clear that, except under certain conditions, trunked systems must monitor prior to transmitting. Stated another way, trunked systems in the affected bands must employ a LBT protocol unless the potential operator has exclusive rights to the channels being trunked or written consent has been obtained from other licensees sharing the channel.

In implementing the new monitoring requirements, the Commission turned to its frequency coordinators[9] to develop and employ uniform procedures concerning the certification of

[7] Two methods were provided to allow applicants for a centralized trunked system to identify the potentially affected licensees. One method is based upon mileage separation and the other is based upon predicted service and interference contours. If the predicted service and interference contours do not overlap, it is assumed that existing licensees would not be subjected to "objectionable" interference from the trunked facilities. 47 C.F.R. § 90.187 (1997).

[8] This statement should not be taken to imply that such written consent is never forthcoming. Because exclusivity and the associated freedom from interference has value to, for example, an applicant wanting to provide services on a third party, private carrier basis, the potential operator of a trunked system may be willing to make cash or in-kind payments (*e.g.*, in the form of new equipment or services) to induce the affected co-channel or adjacent channel operator to provide the required consent. In "Coasian" terms, though, the transactions costs of obtaining such permissions are high and hence economically efficient outcomes may not always be obtained.

[9] Frequency coordinators are entities or organizations that have been certified by the FCC to process license applications and make certain recommendations to the agency regarding what frequencies should be assigned to PLMR applicants. While the role of frequency coordinators is strictly advisory and while the actual license is issued by the Commission, frequency coordinators play an important role in minimizing long term interference between and among licensees operating under Part 90 of the Commission's rules. For further information on the expected role of private frequency coordinators, *see* Federal Communications Commission, "Frequency Coordination in the Private Land Mobile Radio Services," *Report and Order*, PR Docket No. 83-737, 103 FCC 2nd 1093 (1986). .An up-to-date list of frequency coordinators can be found on the FCC Web site at http://wireless.fcc.gov/plmrs/coord.html.

license applications for PLMR systems that require monitoring. The frequency coordinators, under the auspices of the Land Mobile Communications Council ("LMCC"), developed mutually agreed upon monitoring standards, which the Commission accepted and approved [19]. The approved monitoring levels deal with whether the monitoring is done on the input frequency of a repeater/base station or on the output frequency.

As was the case when trunking was developed for use in the 800 and 900 MHz bands, manufacturers responded to these FCC actions with products that complied with the new rules governing trunking in the PLMR bands below 512 MHz. These products included decentralized trunked systems using the LBT procedures described earlier and complying with the specific monitoring requirements discussed above.[10]

Finally, Section 90.187(e) of the Commission's rules provides that "[n]o more than 10 channels for trunked operation in the Industrial/Business Pool may be applied for in a single application. Subsequent applications, limited to an additional 10 channels or fewer, must be accompanied by a certification, submitted to the certified frequency coordinator coordinating the application, that all of the applicant's existing channels authorized for trunked operation have been constructed and placed in operation." In 2004, the Commission rejected an applicant's claim that the ten-channel requirement does not apply to decentralized trunked systems on shared spectrum. It disagreed with the applicant's contention that the Commission did not contemplate decentralized systems at the time it adopted the ten-channel limit and that, because the ten-channel requirement was adopted to prevent the warehousing of spectrum, and shared spectrum cannot be warehoused, the limitation does not apply to shared spectrum.[11]

III. ANALYSIS

This section analyzes the value, in terms of the policy and regulatory precedent, of decentralized trunking for the broader acceptance and early introduction of advanced DSA technology like that developed by SSC under DARPA's XG program. Notwithstanding the complex regulatory history during the 1990s that led to the ultimate adoption of specific rules for non-exclusive, shared, multi-channel PLMR spectrum access through monitoring, it is clear that from the beginning regulators have supported such sharing approaches.

In fact, the notion of using the LBT procedure or protocol as a way of avoiding interference has a long history that goes back to the earliest days of the radio art. As described in section II, above, the idea has been carried through as a manual means of sharing conventional PLMR channels and, more recently, as an automatic means of introducing the spectrum efficiency benefits of trunking in the PLMR bands below 512 MHz. Thus, in general, there is strong precedent for the use of LBT as a means of avoiding interference to existing users of the spectrum. Additionally, the more specific actions taken to facilitate the use of hybrid and decentralized trunking in the VHF and UHF PLMR bands are instructive in terms of precedent for the even more advanced forms of dynamic spectrum sharing. Moreover, the FCC's reliance on the industry, through the LMCC to establish and implement appropriate monitoring requirements, suggests that it will continue to look to industry and standards bodies, such as IEEE,[12] to establish effective spectrum sharing requirements and standards using cognitive radio/DSA techniques. Nevertheless, there remain at least four potential barriers – each of which have certain technical, economic and regulatory characteristics – to near term deployment of DSA systems in the PLMR bands below 512 MHz, but a compelling case could be made to remove them for DSA technologies.

First, as a threshold regulatory matter, it would appear that a radio system using DSA technology to achieve decentralized trunking capabilities could be introduced onto shared channels in the PLMR bands below 512 MHz without any significant changes in the Commission's existing Part 90 rules. Of course, the equipment itself would have to meet the existing Part 90 rules (*e.g.*, out-of-band emission restrictions) and be properly approved through the equipment authorization process, which now accommodates the software defined radio and cognitive radio technologies that are at the heart of DSA systems. Also, the operator of the equipment would have to obtain a station license and be eligible either as a public safety or industrial/business entity. It is also likely, based on the constant improvement of data throughput, that DSA systems deployed in these bands would meet the spectral efficiency requirements established by the refarming rules. However, for true broadband capability, to the extent users seem to demand such capability, it may require some regulatory relief in connection with the current 10-channel limitation imposed by the FCC on new licenses. While the effect of this channel limitation is uncertain, it is clear that the Commission's rules provide incentives to find technical solutions to the spectrum access dilemmas abound in the PLMR bands below 512 MHz.

Thus, from a technical perspective, using advanced LBT functionality to comply with the monitoring requirements for decentralized trunking systems not only facilitates dynamic spectrum access but solves other problems. For example, LBT protocols in combination with DFS capabilities would provide needed flexibility to establish more robust voice and data links in the in the 150-174 MHz band, where current licensees are often forced to employ non-standard channel pairs or un-

[10] One developer and manufacturer of decentralized trunked systems is SmarTrunk Systems, Inc. A description of their decentralized trunked systems is available at: http://www.smartrunk.com/en/index.html. A relevant trade publication article dealing with, *inter alia*, decentralized trunking is D. A. Keckler, "UHF Trunking: Promised Land?," MRT. April 1, 1998, Available: http://mrtmag.com/mag/radio_uhf_trunking_promised/.

The Enterprise Wireless Alliance ("EWA"), a certified frequency coordinator and national advocacy organization for enterprise wireless licensees, providers and manufacturers has revealed that recent manufacturer announcements about the availability of particular VHF and UHF narrowband equipment have prompted EWA and other frequency coordinators to review associated coordination practices and regulatory issues. The frequency coordinators are finalizing a "Best Practices" document and will be proposing to the FCC necessary changes to Section 90.187 to accommodate this new equipment. *See* http://www.enterprisewireless.org/advocacy/.

[11] *See* Federal Communications Commission, "*I2way Petition for Declaratory Ruling*," 18 FCC Rcd 6293 (Wireless Telcom. Bur. 2003), *review denied*, 19 FCC Rcd 8460 (2004).

[12] There are currently two IEEE working groups developing such standards, P1900 (http://www.ieeep1900.org/) and 802.22 http://www.ieee802.org/22/).

paired (simplex) channels.[13] From an economic standpoint, better propagation characteristics in these bands increase link range and reduce infrastructure costs, without displacing or interrupting any other incumbent users, which is often the case with new technology. In the lower UHF band, which is characterized by heavy crowding, at least based on licensing data and especially in metropolitan areas, the monitoring approach opens the door for LBT-based frequency agile equipment to improve spectrum efficiency by accessing unused spectrum and to more effectively avoid interference through automatic deconfliction.

Second, similar to the situation in terms of trunking in the VHF and UHF PLMR bands, a user of DSA technology could, rules permitting, negotiate with existing licensees in various other bands in order to obtain their consent to operate the system on their channels. Just as in the case of centralized trunking in the PLMR bands below 512 MHz, the existing users would have to be convinced that the potential interference, if any, produced by the new operation would be acceptable, even under worse-case situations. Emerging signal detection technology, such as that being developed by SSC and others under the XG Program, is capable of quickly and accurately identifying much weaker signals. Similarly, the device's detection threshold can be dynamically adjusted over a wide range through software policy controls. Such features that enhance the "listening" capabilities of radio transceivers make it much easier to demonstrate and, consequently, to convince existing users that objectionable interference is not a problem. Indeed, SCC is in the process of conducting such demonstrations in various environments and bands.

Third, not only would existing licensees have to be convinced interference is not a problem, but they also must have clearly defined rights to take immediate action in the event that a problem arises along with economic incentives to "share" access with others (*e.g.*, through adequate remuneration, cost reductions or added functionality or capacity). As for assuring interference protection rights (and remedies) this should not be a problem because, in the case of sharing both conventional and decentralized trunked system channels in the PLMR bands below 512 MHz, new and incumbent stations are on essentially equal footing or, to use the term-of-art, they each have "co-primary" spectrum access rights.[14] This means that the new operation must be properly coordinated by the new entrant (through a frequency coordinator) before authorization and construction to ensure it can coexist with incumbents' existing authorized facilities. But in a co-primary situation, the reverse is true as well. That is, once the new station begins operation and transmits on a shared channel, the incumbent station must also monitor to ensure that it does not cause interference. Similarly, if the first licensee wants to expand its coverage or capacity by adding power or channels, such modification is subject to the co-equal protection rights afforded the second entrant. Thus the newer entrant and the incumbent stations are on equal footing as "co-primary" users of the spectrum with no priority access rights available to either, unless such priority is explicitly provided for in the rules (*e.g.*, communications involving the imminent safety-of-life or property"). The expected result is that the incumbents may face increased blocking or congestion delays in accessing the channels when the new entrant is present. This means, in turn, that they may be more reluctant to give the needed consent, if required.

However, as noted earlier, if DSA technology has the proven capability of immediately terminating transmissions on a channel when use of that spectrum by primary users is detected, both the new entrant and an existing licensee seeking to expand operations employing such technology could operate on a "secondary" rather than a primary or co-primary basis. In either case, the secondary user would immediately yield to the primary user once usage is detected.[15] Hence, using this approach, the incumbents would not face the increased blocking and congestion delays that might occur when both parties are operating on a co-primary basis. This should mean that voluntary negotiations with existing users to gain access to spectrum on a shared basis should be relatively easier. A potential question left for regulators would be how to authorize such secondary use in the PLMR bands below 512 MHz since, like the FCC, secondary market leasing of both shared channels and exclusive licenses used for centralized trunking is not permitted.

It thus makes sense, based on a clearly defined hierarchy of spectrum use rights that voluntary negotiations to gain access to spectrum on a shared basis should be further facilitated by the significant steps that the Commission has taken in recent years to remove regulatory barriers to -- and to otherwise facilitate -- the ability of licensees in some services who have obtained exclusive rights to their spectrum to lease all or portions of that spectrum capacity to others. These steps, which were taken in an initiative known as the Secondary Markets proceeding [20], create economic incentives for licensees to allow to their unused spectrum in exchange for cash or in-kind payments on commercially negotiated terms. Succinctly stated, (1) the Commission's actions to create a secondary market in spectrum provides a clear economic incentive for additional spectrum sharing, (2) DSA technology provides a greatly enhanced ability to accomplish that sharing on a non-interference basis, and (3) the Commission's actions to facilitate the use of decentralized trunking in the VHF and UHF PLMR bands provide a strong regulatory precedent for such sharing. However, as noted above, the current prohibition on the leasing of all shared PLMR channels below 470 MHz, including those used for centralized and decentralized trunking, is a remaining

[13] The existence of non-standard and un-paired channel arrangements in the 150-174 MHz band is mentioned in [19].

[14] In regulatory spectrum assignments, a licensed station with primary status is generally protected from receiving "harmful interference" from other, non-primary stations. A licensee with secondary status must protect all primary users in the band from harmful interference (or cease operations) and must accept without recourse interference from primary users in the band. Co-primary users of shared spectrum all have equal rights to operate free of harmful interference. "For the purposes of resolving conflicts between stations operating under [the Part 90 rules, harmful interference is defined as] any emission, radiation, or induction which specifically degrades, obstructs, or interrupts the service provided by such stations." 47 C.F.R. Sec. 90.7.

[15] The effectiveness of a device using DSA technology in minimizing interference by immediately abandoning a channel once use by an incumbent or primary licensee is detected depends upon technical factors such as the periodicity of detection (detection cycles during the transmission) and the abandonment time.

regulatory barrier to dynamic spectrum access to licensed spectrum on a cooperative, leased basis.[16]

Fourth, despite the economic incentives for sharing, the availability of the advanced DSA technology to allow such sharing, and the precedent provided by the Commission's prior actions, the full exploitation of market-based, voluntary sharing may not occur because of prohibitive transaction costs. It is well known among economists that excessive transaction costs can prevent the achievement of economically efficient marketplace outcomes.[17] In the case of the PLMR bands addressed in this paper and in other bands as well, the sheer number of licensees in each band and the few channels licensed by each user may make the costs of negotiating spectrum access prohibitive even though substantial efficiencies in the use of the resource would result.[18]

There are two possible solutions for the potentially high transaction costs. One is to find ways to reduce the transaction costs through the use of specialized intermediaries such as spectrum brokers who aggregate spectrum, identify potential buyers and sellers (or, in this case, potential lessees and lessors) and otherwise assist in transactions.[19] A second solution is "involuntary" or "non-cooperative" sharing under new rules established by the Commission. Under this more risky and time-consuming approach, the types of rules and frequency coordination procedures adopted or sanctioned by the Commission to encourage the adoption of decentralized trunking coupled with the advanced DSA technology can be used to facilitate sharing on an involuntary but non-interfering basis without the need to negotiate spectrum access rights with each incumbent user. For example, in a band in which the fixed stations of the incumbent licensees are individually licensed, an advanced radio of the new entrant could determine its location (*e.g.*, using GPS) relative to the existing stations and determine whether its interference contour on a particular channel is apt to overlap the protected service contours of the existing facilities on that channel. If significant overlap is predicted, the radio could consider other channels.[20] This is roughly the process followed by frequency coordinators and the Commission in introducing centralized trunking in the VHF and UHF PLMR bands. If little or no overlap is predicted, the radio could then monitor the channel for usage and, if it detects none, it could then begin its own transmission at an appropriate power level.

This latter monitoring step is roughly the process that was followed for introducing decentralized trunking with the LBT in those same bands. Note that these two techniques – coordination and monitoring – could be combined in a "belt and suspenders" approach that utilizes interference predictions plus DFS and TPC. By adjusting the interference prediction models, the signal threshold levels and the transmitter power levels appropriately, the statistical probability of interference can be controlled to a level consistent with the needs of the existing service.

IV. Summary and Conclusions

Rapidly emerging DSA radio and networking technology include sophisticated systems that, among other things, take advantage of more intelligent end user radio devices and networking protocols to allow access to currently under-utilized spectrum on a non-interfering basis. The techniques being developed and tested by SSC with DARPA XG Program support use advanced LBT techniques and other interference avoidance measures. The notion of using LBT procedures or protocols as a way of avoiding interference has a long history that goes back to the earliest days of the radio art. Moreover, as described in more detail herein, the basic idea has been carried through as a manual means of sharing conventional PLMR voice channels and, more recently, as an automatic means of introducing the spectrum efficiency benefits of trunking in the VHF and UHF PLMR bands.

Based upon this long history and the Commission's more recent efforts to facilitate the introduction of decentralized trunking, it is concluded that there is significant value inherent in the strong policy and regulatory precedent for facilitating – indeed for promoting as a policy and regulatory matter – the introduction of this advanced DSA technology in order to permit much more efficient use of the increasingly valuable radio spectrum resources. In the U.S., a compelling argument can be made that a DSA radio system using automated LBT technology to achieve decentralized trunking capabilities could be introduced onto shared channels in the PLMR bands without any major changes in the Commission's existing rules or policies.

Using LBT functionality with advanced sensing algorithms, together with DFS and TPC capabilities, could promote shared access via decentralized trunking in the VHF PLMR band, where licensees often employ non-standard

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[16] The FCC did not extend spectrum leasing to shared services "because parties can readily obtain access to the spectrum by obtaining their own authorizations on shared frequencies and they are not foreclosed from applying for authorizations by the existence of another licensee in the same geographic area." In addition, despite suggestions from industry commenters in the proceeding, it determined that PLMR stations below 470 MHz (including those with "FB8" status) would be excluded from these secondary markets policies. While the Commission recognized that there is some degree of "exclusivity" (because the stations are trunked and cannot share in the usual way), the operations nonetheless are still on shared spectrum often occupied by others.

[17] Economists normally identify three types of transaction costs: search costs (the costs of gaining the necessary information about potentially beneficial exchanges), negotiation costs (the costs of negotiating the terms and conditions associated with the potential exchange), and enforcement costs (the costs of enforcing the contract once negotiated). *See* http://economics.about.com/od/economicsglossary/g/transaction.htm.

[18] The principal-agent problem arises when the one party to a transaction – the principal – finds it otherwise advantageous to act through another party – the agent. The principal-agent problem is created because, in some situations, the objectives (or, in economic terms, the "utility functions") of the principal and the agent differ. In a spectrum management context, such a situation could arise when the actual owner of a licensee – the principal, say a city and its taxpayers – could financially benefit from the revenues produced by leasing its spectrum but the city's communications official, the agent, doesn't want to encourage such a transaction because it would add to his/her work without any added compensation.

[19] An example of such an activity is Cantor Fitzgerald's online tool for trading licensed wireless spectrum rights. The tool, called The Cantor Spectrum & Tower Exchange and Marketplace is described in more detail at http://www.cantor.com/spectrum. According to this website "The Cantor Fitzgerald Spectrum & Tower Exchange & Marketplace is a web-based service that makes offering, finding, pricing and executing transfer of wireless spectrum rights, tower assets and tower/rooftop space as efficient, neutral and transparent as possible."

[20] Under the existing rules for introducing centralized trunking in the VHF and UHF bands, this determination is made by private frequency coordinators before the application is transmitted to the FCC's electronic filing system.

channel pairs or un-paired (simplex) channels, and the UHF PLMR band, which is often characterized as overcrowded but underutilized. While this approach will overcome the limited application of the FCC's secondary markets policies that prohibit secondary leasing of these frequencies, one remaining regulatory hurdle for broadband data applications is the 10-channel limit for most new licenses. Further research and development of DSA radios in the VHF and UHF PLMR bands, including actual field testing, may likely provide the technical support to appease skeptical, but bandwidth constrained incumbents as well as domestic and international regulators.

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