Real Time Spectrum Markets and Interruptible Spectrum

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Abstract: **Historically, spectrum use has been increased through use of high frequencies, improved modulation, and between antenna techniques. However, these approaches are reaching practical limits. Cognitive radio allows new approaches to improve the intensity of use in spectrum which is licensed but under utilized. This paper addresses two such possible approaches. Real time spectrum markets permit users to exchange spectrum use. Interruptible spectrum would allow public sector spectrum users to recoup economic benefits for allowing others to share their low average, high peak use spectrum subject to preemption.**

Index Terms: **Cognitive radio, dynamic spectrum, software defined radio, spectrum policy.**

I. INTRODUCTION

Demand for spectrum use is growing rapidly with growing trends in the use of information technology and the increased mobility of our societies. Additionally, interest in using wireless options for broadband access shows that not all the new uses are mobile and fixed wireless access may become a new factor in spectrum demand. Like beachfront property, "they just aren't creating" new spectrum and there are limited realistic options for "recycling" the use of spectrum. In recent decades, technical advances such as use of higher frequencies, improved modulation and coding techniques, and introduction of cellular architecture have increased greatly the intensity of spectrum use significantly. However, spectrum use is now approaching a significant fraction of its Shannon capacity and there are few classic options left for another quantum jump in intensity of utilization.[1]

Cognitive radio (CR) technology builds upon software defined radio (SDR) technology and allows individual radios or groups of radios to make choices about their frequency use based upon their location and the radio use environment. CR technology will not of its own bring quantum jumps in intensity, but it will enable new spectrum management regimes that will. Already the federal communications commission (FCC) has authorized dynamic frequency selection (DFS) for spectrum sharing at 5.3 GHz and has proposed unlicensed sharing of television broadcast bands using a second generation DFS technology. This paper deals with two other spectrum utilization options that could be enabled by CR technology. Both are based on the observation that in the real world there is a lot of "white space"—spectrum that is allocated and licensed but, in practice, not used at a given location at a given time. Both of these methods use marketplace techniques to create incentives for existing spectrum licensees to cooperate in sharing their spectrum with other users. Both of these options have been explored recently by FCC in public proceedings without any definitive resolution.

The two techniques that will be discussed below are interruptible spectrum and real time spectrum markets. Interruptible spectrum is a concept that seeks to increase the utilization of public sector spectrum[2] by letting others share it subject to the requirement that it reverts quickly and reliably to the original user when needed for a surge in public sector communications, e.g., during an emergency. Real time spectrum markets deal with unused spectrum of non public sector entities that is leased to others in a real time market.

Both of the techniques discussed in this paper involve cooperative sharing of licensed spectrum between existing licensees and new users who would pay for permission. To some this might appear as "unjust enrichment" of a spectrum licensee who is not using the spectrum they said they needed. However, in the practical world most licensees view their licenses as a "property rights" regardless of whether there is a legal basis for this view. It is, at best, very time consuming to try to transfer such licensees involuntarily and in practice nearly impossible. The poor record of the FCC in enforcing construction requirements meaningfully, other than for broadcasters, bears this out. Thus, it is probably more pragmatic to reward licensees financially for allowing increased utilization of their spectrum resource for others that to let it continue to lie fallow or underutilized. It should be noted that under present US laws federal government users are unable to retain any revenue that might result from sharing of their spectrum with other users and thus have no financial incentive to participate in sharing.

II. INTERRUPTIBLE SPECTRUM[3]

A. Nature of Public Sector Spectrum Use

A large fraction of spectrum in the US is dedicated to the public sector. This includes both state and local government use regulated by FCC and federal government use regulated by NTIA on behalf of the President. Much of the time, this public sector spectrum constitutes a large fraction of the "white space" as it is sized for peak demands. The NSF-funded measurement report of shared spectrum company shows that even during the 2004 republican convention in New York city—the focus of unprecedented security support—there was significant "white space" in public sector spectrum [1]. It is particularly interesting to compare Fig. 18 of this report showing very heavy observed spec-

[1]The multiple antenna technology known alternatively as space-time coding or MIMO is one promising alternative in this area although its long term potential is still uncertain.

[2]The term "public sector" is used in this paper to denote public safety spectrum used by state and local governments (regulated by FCC) as well as military and civil federal government use (regulated by NTIA).

[3]This concept was first proposed in M. M. Bykowsky and M. J. Marcus, "Facilitating spectrum management reform via callable/interruptible spectrum," in *Proc. Telecommun. Policy Research Conf. 2002*, Sept. 2002. This original paper discusses the concept in more economic terms, available at http://intel.si.umich.edu/tprc/papers/2002/147/SpectrumMgmtReform.pdf.

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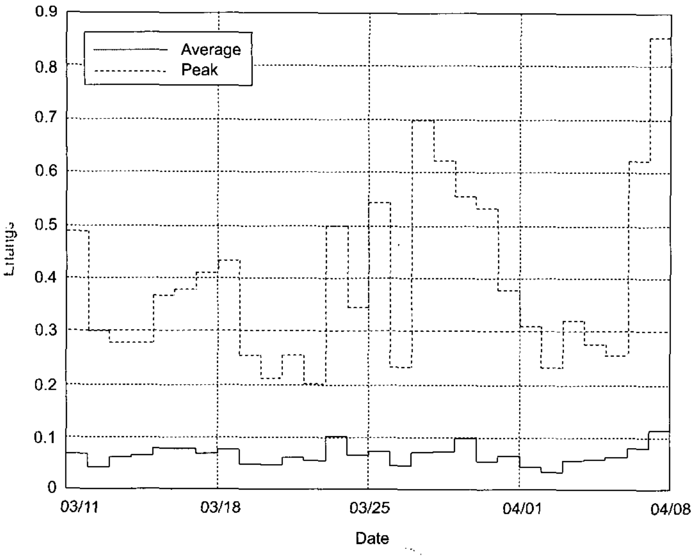

Fig. 1. Peak and average public sector communications demands.

trum use in 174–216 MHz with Fig. 23 showing very light use of 225–406 MHz—all federal government public sector spectrum. Thus, even during peaks of peak public sector spectrum demand there is white space in public sector spectrum!

The military segment of public sector spectrum use, a large proportion of federal government use, is also geographically uncorrelated with civil spectrum use since, with the exception of San Diego, significant military bases are not found in the largest 20 markets.[4] While military spectrum use can occur anywhere in the US, especially aviation use, for practical purposes such spectrum use is low in most large urban markets and thus military spectrum might be used more intensively if a reliable and credible mechanism could be found for sharing it with other users.

Public sector communications requirements include a combination of "base load" requirements for basic administrative needs and normal occurring levels of emergency communications as well as "peak" requirements that are needed for levels of emergency activity which do not occur on a daily basis. An example of this is shown in Fig. 1. In this discussion, the nomenclature "base load" and "peak" are used. These are normally associated with the electric utility industry, not the wireless industry. Interruptible spectrum is modeled after the analogous concept of "interruptible electricity" that has been used for decades in the electric utility industry to match electric load with electric generating capacity in a field where the demand for electricity, like the demand for public sector communications capacity is stochastic.

Public sector communications demand, like electric power demand, has a high peak-to-average ratio even on days without large surges due to emergencies. Sometimes public sector officials are defensive about such descriptions, but they are meant here to be descriptive *not* judgmental. Public sector organizations deal with life and death matters and it is essential that their communications systems must be able to deal with both low average levels and high peaks. The key question here is can we use SDR and CR technology to (1) "recycle" some of the idle capacity in public sector systems at not peak times, (2) provide a financial incentive to public sector entities to cooperate in such "recycling," and (3) possibly find a way for public sector entities to "surge" into other users spectrum, thus extending their?

While some data is available on average and peak public safety communications needs, the author is aware of no data on the time dynamics of such communications. That is, how fast can demand surge in time of crises. Intuition would indicate that it isn't instantaneous because it takes some time for dispersed people to become knowledgeable about the situation. For example, anecdotal evidence about the New York city 9/11 disaster indicate that it took 1–2 minutes for the public sector communications systems to saturate. Passively monitoring of public safety networks together with Markov modeling could be used to develop a better understanding of the time dynamics using techniques developed for telephone traffic.

B. Interruptible Spectrum Design Issues

With knowledge of the time dynamics of public communications demand, one could design a system to give public sector users full time access to a fraction of their spectrum which is large enough to meet their peak needs a large fraction of the time, say 9 out of 10 days and then meet demand surges by preempting spectrum leased to others. The other spectrum could be preempted all at once or in stages as public sector demand grew. For example, one might have 30% of the channels reserved for full time pubic sector use and set a usage threshold of 20% of the channels at which time an additional 30% was preempted and reverted to public sector use, yielding a total of 60% of channels. A second threshold at 45% usage might trigger the preemption and return of all channels.

Clearly, the channels that would be rented by nonpublic sector users would have unusual characteristics since they could be preempted. But isn't that what communications engineering is about? Taking channels with odd characteristics, enhancing them with technology, and creating networks that meet real needs.

Interruptible electricity has a real market but not the market for residential lighting. Interruptible water supplies are available to agricultural users at a lower price than more reliable water. And finally in the satellite industry there is already a market for preeemptible transponders. In all these cases, customers are users who can tolerate interruptions and are pleased to pay a lower price.[5] Such potentially interruptible applications may also exist in spectrum use. The growing demand for blackberry-like PDAs and cellphone SMS messaging are essentially store-and-forward messaging services. Such applications readily adapt to changes in signaling speed. Building such store-and-forward systems out of a combination of dedicated normally licensed spectrum and interruptible spectrum would allow the operator to temper changes in capacity while also benefiting from the reduced spectrum access cost of interruptible spectrum.

[4] A map showing locations of domestic US military installations in 1993 can be found at http://www.cr.nps.gov/nagpra/DOCUMENTS/BASES.PDF. There are fewer bases today.

[5] A classic set of customers for interruptible electricity are industrial users for whom power costs are significant fraction of their overall costs and who can safely decrease demand on short notice, as in aluminum refining by electrolysis.

Table 1. Interruptible spectrum options.

Option	Description	Reliability for public sector interruption	Reliability for commercial user	Complexity
I	Transmit until told to stop by public sector user	Low	High	Low
II	Handshaking on order wire before each transmission	High	Medium	High
III	Carrier sense multiple access (CSMA)	Low	High	Low
IV	Turn off signal from public sector user with acknowledgement	Medium	Medium	Medium
V	Beacon signal for positive control	High	Medium	Medium

Some cellphone users also might be willing to pay less for their service in exchange for occasional "dialtone" delays.

Because public sector communications is so critical, any new approach to using public sector spectrum must meet certain special requirements. The first responders whose lives depend on reliable radio communications must be able to understand the basics of the systems and must trust it. The system must be ultrareliable and robust in the face of overloads and deliberate attacks. When in doubt, the system must give priority to public sector needs.

Table 1, below describes 5 possible concepts for implementing interruptible spectrum. These are classified according to their reliabilities for the point of view of both public sector users and commercial users as well as their complexity.

In Option I, commercial users of interruptible spectrum could transmit until they receive a specific signal telling them to have the signal revert to the public safety user. Such a system would have low complexity, but also low reliability as the reversion signal might be missed.

In Option II, the commercial user must request permission over an "order wire" channel before each transmission. This gives very good reliability for the reversion of the channel, but also increases the complexity.

Option III is the traditionally CSMA in which the commercial users just listens for public sector use and then uses the channel if idle. This is found to have low reliability of timely reversion.

Option IV would have a turn off signal from the public sector users as in Option I, but would require a specific acknowledgement from the commercial user. This increases complexity but does not lead to high reliability.

Option V, the preferred approach of the author, involves a beacon system controlled by the public sector user that must be monitored by the commercial user who must stop use unless he has properly verified the time-coded signature of the beacon within the past x seconds. This results in a fail-safe situation with respect to jamming, spoofing, or adverse radio propagation.

C. Regulatory Status of Interruptible Spectrum

The FCC initially considered the general concept of interruptible spectrum in the *Cognitive Radio* proceeding. Interruptive spectrum was included in the *Notice of Proposed Rulemaking* in Docket 03-108 [3] and the public comments showed that proceeding that the topic was very controversial. Many state and local public safety entities were concerned that the concept would open "Pandora's box" and they other public safety entities would compromise public safety in exchange for revenue.

In the *Report and Order* of the proceeding, the Commission found

> ... that cognitive radio technologies, or even trunked radio technologies, would allow implementation of the following general principles that interested parties state would be essential to enable interruptible leased use of spectrum.
> 1. The licensee must have positive control as to when the lessee can access the spectrum.
> 2. The licensee must have positive control to terminate the use of the spectrum by the lessee so it can revert back to the licensee's use.
> 3. Reversion must occur immediately upon action by the licensee unless that licensee has made specific provisions for a slower reversion time.
> 4. The equipment used by the licensee and the lessee must perform access and reversion functions with an extremely high degree of reliability.
> 5. The equipment used by the licensee and the lessee must incorporate security features to prevent inadvertent misuse of, and to thwart malicious misuse of, the licensee's spectrum. [4]

The 5 points appear to be consistent with Options I, II, IV, and V in the enumeration above. This would give implementer of interruptible spectrum in the US multiple technical approaches to try.

The *Cognitive Radio* proceeding dealt with the technical issues but did not addressed the more basic policy issue of whether FCC public safety licensees could lease their spectrum at all. This was addressed in the parallel *2nd Report and Order* in Docket 00-230, where FCC gave very limited approval to spectrum leasing, such as interruptible spectrum, for public sector entities saying,

> With regard to the public sector services in part 90, we will permit public sector licensees with exclusive use rights to lease their spectrum usage rights to other public sector entities and entities providing communications in support of public sector operations. We, however, decline at this time to permit public sector licensees to enter into spectrum leasing arrangements for commercial or other non-public sector operations. [5]

At the time of preparation of the cognitive radio NPRM, FCC explored with NTIA the possibility of mentioning that interruptible spectrum might also be applicable to federal government spectrum but NTIA declined. The author is not aware of any public occasion in which NTIA has explored the applicability of interruptible spectrum.[6]

Thus, interruptible spectrum in the US is allowed at present in a limited way by the above two recent FCC decisions. It is unclear what was intended by the phrase "entities providing communications in support of public sector operations." Perhaps

[6]While NTIA filed comments in Docket 03-108, these comments only mention interruptible spectrum in passing and never discuss its merits. Comments of NTIA in Docket 03-108 at p. E-39, available at http://www.ntia.doc.gov/ntiahome/fccfilings/2005/cogradio/ETDocket03-108_ 02152005.pdf. Neither interruptible spectrum nor cognitive radio are mentioned in the report "Spectrum policy for the 21st century—the President's spectrum policy initiative" prepared by NTIA and the federal government spectrum task force, June 2004 http://www.ntia.doc.gov/reports/specpolini/presspecpolini_report1_06242004.htm showing NTIA's apparent disinterest in these topics.

this might mean a carrier providing wireless communications services to both public sector and other users. If so, it could provide a toehold for this technology. "Public sector users" actually encompasses much more than police and fire department operations so it is now be possible for police and fire users to implement interruptible systems with other local government operations. However, it is not clear if there are any financial incentives for local governments to implement such systems. As was previously mentioned, federal government users have no financial incentive to participate in interruptible spectrum schemes. But technology companies might want to exploit the FCC provisions to demonstrate their technology and increase the confidence of the public sector community.

III. REAL TIME SPECTRUM MARKETS

A. White Space and Variable Demand

Traditionally spectrum licensees have multiyear licenses that they can use only for their own use or, for certain classes of licenses,[7] can provide service to the public. While temporary licenses are possible for special events, obtaining them in nonemergencies is time consuming. Thus, there is little a user can do who has a sudden unanticipated need for spectrum even if other spectrum users in the area have idle spectrum. Real time spectrum markets would be a possible way to address this problem. For the past decade, the electric utility industry has been using a spot market in electric power to match supply and demand on an hourly basis. In both cases, an organized market with well defined procedures can bring together buyers and sellers to the benefit of all.

FCC has already recognized the possible long term need for real time spectrum markets. In its cognitive radio R&O it stated, "cognitive radios may eventually enable parties to negotiate for spectrum use on an ad hoc or real-time basis, without the need for prior agreements between all parties." [6]

Under traditional radio licensing licensees could arrange a *de facto* sale of their spectrum to another user, but could not lease or loan spectrum to other users without specific regulatory approval. "White space" is an inevitable result of these traditional policies since licensees have little marginal cost for holding on to unused or lightly used spectrum, have no incentive to improve their efficiency if their present technology gives them adequate capacity, and have high transaction costs associated with selling their spectrum.[8] White space also results from licensees with diurnal or seasonal variation in their communications demands. Such licensees, can not under present policies seek intermittent spectrum to meet their likely peak demands and thus seek adequate full time spectrum to meet their peak demands.

B. Existing Secondary Market Policies

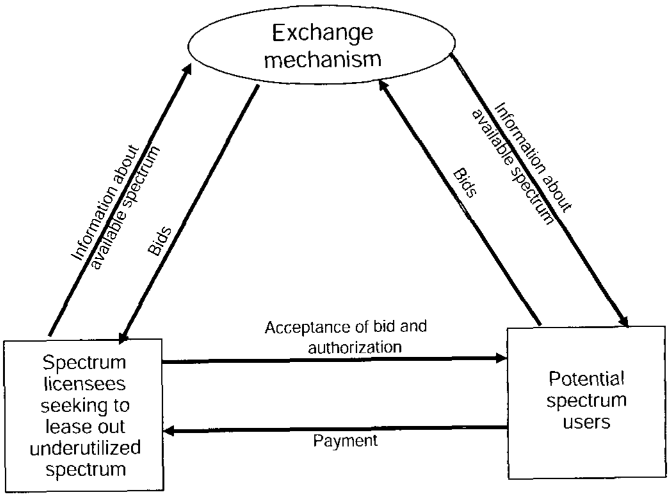

Fig. 2. Mechanisms for a real time spectrum market.

Since May 15, 2003 FCC has allowed "secondary markets" for some classes of radio licensees [7]. The rules were expanded and clarified on July 8, 2004 [8]. These rules now permit many classes of FCC licensees to lease spectrum on a long term or "dynamic" basis.[9] It is expected that these US rules will be liberalized more in the future and that other countries may move down the same path.

While the FCC secondary market rules are the beginning of a legal framework for real time spectrum markets, there are a lot of practical issues that must be addressed before they become practical. As explain below, the new FCC secondary market rules limit the time dynamics of leases. Other issues are the general issues necessary for an efficient market to work and to bring together buyers and sellers so opportunities can be readily identified and prices can be agreed upon. The reason why pork bellies, grains, and crude oil can be efficiently bought and sold on various commodity markets is that there are standards definitions of units for each of these commodities and standard formulas for dealing with lots that vary from known standards.

C. Creating a Real Time Market

Fig. 2, shows the basic requirements of a functioning real time spectrum market. An exchange mechanism is needed to bring together potential spectrum users and spectrum licensees seeking to lease out spectrum.[10] The exchange mechanism would facilitate the exchange of information in terms terms of standardize contracts just as commodities markets do.

In Fig. 2, buyers and sellers communicating directly for final authorization and payment are shown. This is a different practice than in commodity markets but is probably necessary

[7]Formally called commercial mobile radio services (CMRS).

[8]In the US, sale of "naked" spectrum is not permitted since licensees must waive any claim to the spectrum, 47 USC 304. However, de facto sale of most types of radio licenses has been going on for decades through the guise of selling the "business and assets" of the corporation that holds the license. This can be confirmed by reviewing advertising in various radio trade magazines over the years. The record price for a TV station is $800,000,000 for "good will and physical assets." Is there any doubt that most of this value was the spectrum license?

[9]While FCC seems to favor "dynamic" spectrum access, see para. 88–90 of above Docket 00-230 decision, the time dynamics appear to be constrained at present by the details of 47 CFR 1.9035(e) which allows for "immediate approval procedures" but then specifies that "consent will be reflected in ULS (an FCC database system) on the next business day after filing of the application." Removing any doubt on whether you have to wait for this consent is the additional requirement. "Consent to the application is not deemed granted until the bureau affirmatively acts upon the application, as reflected in ULS."

[10]Note that these last two groups of users might overlap as some spectrum licensees may wish to lease out spectrum to others at times of their own low demand, but then lease additional spectrum when their demand peaks.

in a spectrum market. FCC rules require that the licensor is responsible for the use of his spectrum during the lease, unlike the situation in which a pork belly seller has no need to know who buys his commodity. Direct payment may not be necessary, but is simple with today's electronic payment systems and would be analogous to the well known e-Bay procedure of direct payment. Finally, spectrum leasors may want assurances that the spectrum is used consistent with the terms of the lease and ends when the lease ends. This is an issue that has to be addressed when standards are developed for real time spectrum markets. If the consensus is that strict control is needed, software products similar to Macrovision's FlexNet[11] could be used as a base to develop a system where leasors send specific keys to leasees to enable the specific package of rights that have been leased.

D. Benefits of Real Time Markets

Real time markets could unlock a large the which space found in urban spectrum use today. Existing licensees could find real financial benefit to using their white space. While many licensees think they are not in the communications business per se "sharp penciled" managers might start seeing the firms' radio licenses as a possible income producing asset rather than an intangible assets just like electric utilities realized that their transmission line system could become an independent revenue source if they allowed them to be used for fiber optic communications alongside with power transmission.

The FCC's proposal for unlicensed use of white space in the TV bands [9] is presently paralyzed over a concern that it might interfere with transient use of idle spectrum on a part 74 licensed basis for the cordless microphones at outdoor news events and sports events [10]. Real time spectrum markets could be a way for broadcasters to buy spectrum access on an equal footing with other spectrum users according to their requirements and budgets.

E. Cost/Feasibility Issues

There is complexity in implementing any of these schemes, but given the amount of computational power included in most radio systems it appears that the computational power is there to provide the systems. In the USA, the approximate value of UHF spectrum usable for mobile systems is US$1.50/MHz/unit of population, for US$1, 500, 000/MHz for a city of 1 million population. This shows the value that can be achieved if these techniques can be used to create "new spectrum" and the cost advantages they would have over alternatives that must purchase spectrum at market value.

IV. CONCLUSIONS

Interruptible spectrum and real time spectrum markets are two approaches to utilizing white space to enable more intensive use of the spectrum. Both have been addressed by FCC recently and been approved in limited ways. Unfortunately, NTIA has been unwilling to date to consider these or other cognitive radio approaches as part of the future of national spectrum management. Consideration of these type of cognitive radio approaches by NTIA, other national regulators, and the ITU could lead to more effective spectrum use, economic growth, and technical innovation.

[11] FlexNet is widely used in high value software packages, e.g., Matlab, to control the number of users at a given time and other use parameters. See http://www.macrovision.com/products/flexnet/index.shtml. A similar system could be designed for SDR units that would permit operation only on the frequencies and powers specified in the key generated by the leasor at the time of lease completion.

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