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In the Matter of

Issues related to the
Commission's
Spectrum Policies

More Market Mechanisms, in Moderation (M^4)
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Overview

Spectrum scarcity is a debilitating affliction. Today, the US faces a scarcity that is severely exacerbated by our spectrum management policies. Technology has changed dramatically, and policy must keep pace. I commend the Federal Communications Commission for initiating this public debate. Policies that encourage users to put spectrum to its most valuable use can make scarcity more tolerable. To alleviate the scarcity, we must find new methods to allow and encourage efficient spectrum *sharing*; exclusivity can lead to inefficiency. Today's technology offers many ways to gain the efficiencies of sharing without unacceptable interference.

The Commission should expand use of market-based mechanisms, and the Commission should insure the availability of an unlicensed spectrum "commons." Taking either one of these approaches to a simplistic extreme would be counterproductive, so the Commission should make judicious use of both. There is no substitute for an effective regulator.

1. *What specific policy and rule changes are needed to migrate from current spectrum allocations to more market-oriented allocations?*

Market-based mechanisms can be used to determine

1. who gets access to spectrum,
2. how spectrum rights are packaged,
3. what can be done with spectrum, and
4. the cost of holding spectrum.

1) Thanks to auctions, new licenses are assigned to those who value them the most. It should similarly be easy for a license-holder to "sell" a license, where the post-sale license-holder has rights and obligations that are identical to those of the previous license-holder. Similarly, a license-holder might "rent" the license for a limited time, which obviously cannot extend beyond the expiration date of the license.

2) The simple tools above can help define how spectrum is packaged. The Commission must decide the bandwidth and geographic area associated with each license. This decision may make some spectrum useless for some applications, and it significantly affects efficiency. For example, dividing a fixed bandwidth of cellular spectrum into more blocks improves competition, while simultaneously decreasing the amount of traffic that can be carried in that spectrum [1]. By allowing license-holders to subdivide spectrum blocks and "sell" or "rent" portions, within the constraints described in the paragraph above, the market can influence the

size of these spectrum blocks. In theory, subdivisions can occur by frequency range, geographic area, time, or even by interference level (e.g. through code division).

There has been considerable discussion about creating a secondary market where these blocks of spectrum can be rented out for months or years. It is important to note that more dynamic forms of sharing, where spectrum is given out for minutes or milliseconds, are also possible. The license-holder would grant a secondary user temporary access to spectrum, and would perhaps guarantee that interference levels will be below a specific threshold, in return for a fee. As one example, we have analyzed the case where the license-holder is a cellular carrier [2]. The carrier uses GPS data to help determine whether a secondary device would significantly affect cellular calls. If so, the request is denied. We have shown that a cellular provider could charge very little for this kind of access to spectrum and still profit. The arrangement is attractive to secondary users provided that, when their request for access to spectrum is denied, they can either wait or try a different band. With the emergence of software-defined radios, it becomes possible to build inexpensive devices that try for access on many bands until finding one that is available. This kind of highly dynamic secondary market could increase the traffic carried within these spectrum bands, thereby improving spectral efficiency and alleviating the shortage.

3) The third type of market-based mechanism listed above determines what a user can do with spectrum. These "flexible use" models are discussed in response to the next question.

4) The fourth and final area concerns the cost of spectrum. Today, an auction-winner is likely to pay an enormous one-time fee for access to spectrum, and nothing thereafter. This creates many problems. First, if the day comes when the license-holder is deriving only slight benefit from the license, there is still no incentive to relinquish that license. Second, reasonable bids for a one-time fee should reflect how long the license can be held, and bidders have no way of knowing how many times they will be allowed to renew a license. Third, the high initial cost makes it difficult for small companies to compete in auctions. Finally, there can be a temptation for government officials to choose the timing of an auction based on budgetary concerns, rather than on maximizing the utility of an important national resource. A proposed solution [3] is to replace this one-time payment with annual spectrum fees; the winner of the auction is the entity that offers to pay the highest annual fee for as long as it holds the license.

The imposition of spectrum fees for incumbent license-holders is more problematic. However, for those incumbents who are given greater flexibility of use, greater ability to profit from their spectrum through secondary markets, and/or greater opportunity to sell their license to the highest bidder, all of which increase the value of the license, perhaps they can simultaneously be assigned an annual spectrum fee if a fair method can be defined.

2. *Should current, restrictive service and operating rules applicable in many bands be changed to provide licensees with greater flexibility? If so, in which bands and how?*

The Commission should continue to expand flexibility in bands where demand for current applications is uncertain, or uneven across the country, but flexibility should be kept within limits, and it need not be expanded to all bands to gain the basic benefits of flexibility.

Flexibility can greatly enhance the value derived from spectrum [3]. It allows a license-holder to use spectrum for the most valued application, or if other market mechanisms are in place, to transfer the spectrum to someone who will do so. Too much spectrum is dedicated to applications of marginal value because license-holders are prohibited from choosing a more valued and valuable application. Flexibility also allows a given frequency range to be used for different purposes in different parts of the country, which is critical since the needs of rural and urban areas can differ tremendously.

However, flexibility comes at a cost. There is value to regulator-imposed uniformity [3]. Consumers can move anywhere in the country, and their televisions will still work. If television had emerged in an era where complete flexibility prevailed, it is possible that incompatible standards or frequency ranges would have emerged in different regions. Following such a standard yields a positive externality, which can lead to market failure. Some degree of national uniformity is also helpful in international fora. There are also applications that require a high-bandwidth contiguous block of spectrum, and regulators can make this possible, where it may be difficult to assemble all the pieces in an open market due to the transaction costs.

Another disadvantage of flexibility, if it is taken too far, is that interference levels must be sufficiently low that they do not interfere with anything a license-holder is allowed to do - regardless of what the license-holder is actually doing. Thus, increasing the license-holder's flexibility also decreases the discretion of a regulator to adapt to new needs and new technologies. For example, the Commission recently made an important decision to allow ultrawideband devices to operate between 3.1 and 10.6 GHz. Luckily, none of the incumbent license-holders in that range had enough flexibility to successfully argue that ultrawideband would infringe on their rights. When extending flexibility, the Commission must similarly maintain enough authority to clear the way for the next important innovation - whatever it is.

This is one reason why the Commission should *not* consider making spectrum rights permanent. Licenses must expire, so that regulators have the opportunity to introduce change.

3. *Should spectrum policy be different in different portions of the spectrum or in different geographic areas?*

Spectrum policy should continue to differ from one band to another, as this is the best way to gain some degree of national uniformity in conjunction with flexibility.

It is also useful for different geographic regions to use spectrum differently. For example, fixed wireless is an effective way of delivering broadband last-mile access. At least in greenfield deployments, it compares very well with DSL and cable modems where population density is low, but not where population density is high [4]. Thus, availability of spectrum for fixed broadband access may be extremely important for rural areas, whereas urban areas probably have greater need for spectrum to support basic mobile telephony.

I strongly support the idea of getting accurate measurements of spectrum use and congestion in many bands and in many parts of the country. (We at Carnegie Mellon University have already experimented with these kinds of measurements in Pittsburgh.) This data can be valuable in evaluating spectrum policy options. However, developing standards that use this data to categorize regions as "congested" or "uncongested" would be difficult. Results are highly dependent on exactly how, when, and where measurements are made.

Uniform definitions of "congested" regions are unnecessary if license-holders have sufficient flexibility to choose the best application for their region. Still, as usual, the Commission can make the environment more or less conducive to efficient use. In this case, they do so when they determine the geographic areas associated with licenses. For example, this kind of rural-urban differentiation is more likely to occur in Pennsylvania if the urban areas of Pittsburgh and Philadelphia are not packaged in the same license with the more rural area between these cities.

5. *Should more spectrum be set aside for operating unlicensed devices? Should the kinds of permissible unlicensed operations be expanded? What changes, if any, should be made to the rules to accomplish this? Because of the commons aspects of unlicensed use, is there concern that, as congestion rises, spectrum may not be put to its highest valued use? If so, what policies might be considered to anticipate this problem?*

Recent allocations of unlicensed spectrum have spurred tremendous innovation and productivity, as best demonstrated by the rise of wireless LANs, and this is just the beginning. The Commission should insure that adequate spectrum is available for unlicensed devices.

In 1993, Carnegie Mellon University (CMU) began development of an experimental wireless system designed to blanket campus with broadband coverage, both indoors and out. CMU used a precursor of what later became the 802.11 standard. This system has become an important part of campus infrastructure, and organizations around the world are now deploying similar systems. CMU could never have developed this system if unlicensed spectrum was not available. I suppose CMU could have obtained a license, giving us exclusive access to a block of spectrum

throughout the neighborhood, but this would have been exorbitantly expensive, and deservedly so. Exclusive access would be an incredibly inefficient use of spectrum. Computer communications are highly bursty, and some collisions are tolerable, so it makes sense for CMU, the University of Pittsburgh, several large hospitals, and many small business and individuals in our neighborhood to share the same block of spectrum. Alternatively, CMU could have tried to get highly localized site licenses for all transmitters, and coordinated their locations with our neighbors and/or with the FCC. However, this might require the university to contact the FCC every time one of our 650 transmitters was deployed or moved. The transaction costs of explicit coordination would exceed the value of the system. Finally, CMU could have called a licensed wireless service provider, who might have offered us a carrier-based 3G-like service that was more expensive, less flexible, less useful, and less spectrally efficient for our particular application. This is just one example of a system that can flourish in unlicensed spectrum, but would fail if a license were required, with or without market-based mechanisms.

As demonstrated by the example above, unlicensed spectrum has many advantages. It requires spectrum sharing, which can lead to vastly superior spectral efficiency than exclusive access, where spectrum often sits idle because the license-holder is not transmitting. Unlicensed spectrum is necessary to support mobile systems, such as a group of laptops that form an ad hoc wireless local-area network wherever they happen to be. It is useful for inexpensive low-power consumer products such as cordless phones, where the cost of coordination and licensing would unnecessarily dominate system cost and the interference impact on neighbors is small [5].

Unlicensed spectrum should not be seen as a replacement for licensed spectrum, any more than public parks are a replacement for private homes. In releasing unlicensed spectrum, the Commission must guard against two related dangers. One is that unlicensed spectrum will attract applications that would operate more effectively and efficiently in licensed spectrum. The other is that devices will transmit with greater power, duration, or bandwidth than they need, because they have little incentive to conserve the shared resource [6]. Both of these dangers can be addressed effectively by establishing appropriate rules to govern the unlicensed bands, possibly (but not necessarily) influencing power levels, modulation, back-off schemes, etc. At minimum, these rules will prohibit a device from transmitting at high power for extended periods without interruption. These rules can also be designed with built-in incentives to conserve spectrum [7,8,9].

For those who want to raise revenue from all spectrum, it is possible to add a fee per unlicensed device. However, if such fees are adopted, great care is necessary. The $20 fee currently imposed in the unlicensed PCS band has made it impossible to deploy inexpensive unlicensed devices in this band, because this fee will dominate cost. This is one reason the asynchronous band has not been useful. (Although not the only reason) This $20 fee should be greatly reduced, at least for inexpensive low-power devices.

16. *Some parties assert that the Commission should adopt rules for interference that are based on economics, and not purely technical, in nature. They argue that efficient interference management should involve an economic balancing between the parties using the spectrum. Would greater use of these types of alternatives lead to more certain and expeditious resolution of interference issues?*

The best judges of economically efficient interference standards are the parties causing and experiencing the interference. The Commission could establish default technical rules on interference among license-holders, and then allow those license-holders to negotiate levels that differ from those established from the Commission under some conditions, perhaps in exchange for a fee. The net effect is that one party is "renting" spectrum from another by changing the boundary between them. Such agreements can be beneficial for all parties, and can serve the public interest. All parties involved must also remember that private agreements have their limitations, and are not an exact substitute for action by the Commission.

- All affected parties must agree. This implies that the process must be sufficiently open that any licensed or unlicensed spectrum-user will have the opportunity to object due to concerns about interference.
- Agreements can only constrain those who agree. This implies that such agreements may become meaningless if a license of one of the parties expires and is not renewed, or if the Commission grants some new party access to affected spectrum.

16. What new technologies exist that, if deployed, could improve spectral efficiencies and utilization? What are the barriers to their deployment?

Two particularly important emerging technologies are software-defined radios and ultrawideband, both of which could help to relieve spectrum scarcity. Ultrawideband has vast potential, and I applaud the Commission for their actions last February. I recommend that the Commission revisit the issue in 2003 when there are commercial ultrawideband systems in the field, to see whether current restrictions should be modified.

I will not attempt to summarize the entire software-defined-radio docket here. I will simply repeat (from a response to question 1) that an essential piece of any solution to spectrum scarcity is improved spectrum sharing, and the software-defined radios can play an important role in facilitating spectrum sharing.

19. *Should the Commission consider ways to quantify or benchmark spectral efficiency in a way that permits fair and meaningful comparisons of different radio services, and if so, how would such comparisons be used in formulating spectrum policy?*

The development of meaningful measures to benchmark spectral efficiency is an important and unresolved issue. The Commission should encourage and follow this research, as quantitative measures may help the Commission to make good decisions. Inefficient use of spectrum is one indicator that a policy change may be in order. However, it will be difficult to define a single measure that is meaningful for a wide variety of applications and deployment environments without the subjective judgment of experts.

23. *Recognizing that many of these special needs for communications capacity are highly variable in time and location but generally low in average traffic level, should the Commission and these users consider novel sharing mechanisms for such spectrum that might be appropriate and what criteria (e.g., very high reliability) would need to be used to determine whether such sharing is advisable?*

The Commission should definitely pursue novel sharing mechanisms that are well suited for public service organizations. There are many public service applications that rarely need access to spectrum, but when they do need spectrum, their need is urgent and important. These applications could easily share spectrum with commercial applications that can tolerate occasional interruption. There are many technically reasonable ways to provide this sharing, in which the public service agency would be adequately protected, the commercial user would gain access to a useful resource, and the spectrum would be used more efficiently. The non-technical problem is that these agencies typically have no incentive to share under today's policies. They typically gain nothing from whatever fees the secondary commercial user might be willing to pay, and the public service agency is likely to incur the cost of coordination as well. To address these issues, the Commission will probably have to work closely with other government organizations.

References

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