Increasing Wireless Value: Technology, Spectrum, and Incentives

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February 2013

Abstract:

Demand for wireless service has been growing rapidly. But while quantity of wireless service (measured in terms of bytes or minutes) has increased dramatically, price has increased little, if at all. This paper examines how supply of wireless capacity has increased and how it can continue to increase in the future. Given that there is little prospect for finding currently unused spectrum, the government should institute policies that promote the economically efficient use of spectrum currently in use, which in turn could make spectrum available for alternative uses. The best way for the government to promote spectrum efficiency is to ensure that users have flexibility and that they realize the opportunity cost of their use of spectrum. Two areas where users do not realize the opportunity cost of their use of spectrum are broadcasting and government and rules regarding those uses can be revised. In addition, the government should adopt market mechanisms to determine the opportunity cost of spectrum designated for unlicensed use.

Keywords: Spectrum, Broadcasting, Regulation

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Communications services have changed substantially over the past 50 years. In 1963, about three quarters of U.S. households had a landline telephone with very expensive long distance charges.[1] Just over 90% of households had televisions, typically receiving the signals of three national television networks and possibly a few local television channels, broadcasting in black and white.[2] Approximately 2,000 computers were in use in the entire United States.[3] The U.S. Postal Service handled about 1 letter per person per day.[4]

In the 1970s, 1980s and 1990s, the spread of cable television, the introduction of cellular telephony, and the rise of the Internet changed how people communicate. Even over the past ten years, changes have continued, with the advent of texting, smartphones, video conversations, and the like. Demand for wireless service has been growing rapidly. But while quantity of wireless service (measured in terms of bytes or minutes) has increased dramatically, price has increased little, if at all. Because price has not increased while the demand curve has shifted dramatically for wireless communications (tastes, capabilities, etc.), the supply curve must have shifted dramatically as well.[5]

Most predictions are that demand will continue to shift outwards as tastes move to wireless and wireless devices continue to become more attractive. So, shifts in the supply curve must continue or prices will increase.

This paper will examine how supply of wireless capacity has increased and how it can continue to increase in the future. At a high level, there are three ways to increase wireless capacity: increasing the amount of spectrum used (or increasing the value of the use of spectrum); increasing the use of capital involving a particular technology (e.g., more cell sites) with the spectrum; and increasing the technological capability of the capital employed (e.g., more technologically advanced cell sites, or somehow reducing contention for spectrum use) for wireless transmissions.

The first mechanism for increasing wireless capacity is to make additional spectrum available. However, very little spectrum is not currently allocated to any specific use, so that increasing the amount of spectrum available for one use necessarily entails an opportunity cost –some other use that would be precluded or limited.

Given that there is little prospect for finding currently unused spectrum, the government should institute policies that promote the economically efficient use of spectrum currently in use, which in turn could make spectrum available for alternative uses. The best way for the government to promote spectrum efficiency is to ensure that users have flexibility and that they realize the opportunity cost of their use of spectrum. The government can do this by removing restrictions on use, transferring transmission rights from the

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[1] U.S. Census (2003).
[2] U.S. Census (2003). In addition, on December 7, 1963 CBS showed the first instant replay in the Army Navy football game. Computer Hope (2013)
[3] Computer Hope (2013)
[4] U.S. Postal Service (2012)
[5] Wireless output used to be measured in terms of voice minutes of use. But now output needs to be measured differently – in terms of data usage, which includes voice and text. CTIA (2012).

government to the private sector, and ensuring that open access spectrum is appropriate, both in quantity and in terms of the frequencies it occupies.

Such government policies also facilitate the second and third mechanisms for increasing wireless capacity. If users internalize the opportunity cost of spectrum use, they will make appropriate investments in capital and the introduction of new technology.

I. Increasing capacity on spectrum that is flexibly allocated

Hatfield and Ax (1988) use an engineering model to show the tradeoff between using spectrum and splitting cells (using additional capital) in a cellular system. While the technologies have changed, users still make a calculation between acquiring spectrum and investing in additional infrastructure to increase capacity.

Licensees have incentives to use flexibly allocated spectrum efficiently and have increased the technical efficiency of the transmissions on their licensed spectrum. There are two ways to increase the technical efficiency for a given amount of spectrum: increasing the amount of capital and enhancing the technology used with the spectrum.

Currently, the FCC has allocated about 547 MHz for commercial licensed flexible use spectrum below 3.7 GHz of which it indicates that 442 MHz is suitable and available for mobile broadband service (including 156.5 MHz below 1 GHz).[6] It has also allocated 955 MHz for unlicensed use in a variety of bands.[7] The FCC had hoped to increase the amount of flexible use spectrum by making "500 megahertz of spectrum newly available for broadband within 10 years, of which 300 megahertz should be made available for mobile use within five years."[8]

Licensed wireless service providers have invested over $347 billion to build the infrastructure necessary to provide "cellular" service where the frequencies assigned to them can be used many times within a metropolitan area.[9] Building more cell sites and reducing the range of transmission increases the frequency reuse and hence increases system capacity. However, each cell split becomes more complex with fewer locations for transmitters and increased cost for backhaul and cell handoffs. In addition, it may be difficult to reduce power and achieve coverage (especially within buildings) at the same time.

Advances in technology have also led to substantial increases in capacity. Originally, cellular systems were based on the FCC-mandated Analog Mobile Phone System (AMPS) standard developed by Motorola and Bell Labs. In the 1980s, capacity worries

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[6] Cellular (50 MHz), PCS (120 MHz), SMR (26.5 MHz), and 700 MHz (80 MHz) spectrum, as well as AWS-1 (90 MHz) and BRS (55.5 MHz) Wireless Communications Service ("WCS") (20 MHz). FCC (2011b) and FCC (2012a). The FCC hopes to transition up to 120 MHz of spectrum in the 600 MHz band from television to flexible use in the next few years. FCC (2012a)
[7] Hazlett and Leo (2010)
[8] FCC (2010a)
[9] CTIA (2012) reports that there were over 285,000 commercial cell sites.

led wireless providers to move toward more advanced digital technologies. In 1994, the FCC declined to adopt any particular standard for U.S. wireless (in contrast to Europe's adoption of GSM) and carriers adopted at least three major flavors of 2G technology (GSM, TDMA, and CDMA). 2G technology led to a capacity increase over AMPS. The move to 3G and now to LTE technology has generated further increases in capacity over 3G and AMPS.

The orders of magnitude increases in wireless usage has been driven by increased spectrum, increased capital investment in cell sites and backhaul, and increases in technological capability as carriers install newer, more spectrally efficient technology.

At the same time, there has been substantial increase in the capacity from and usage on unlicensed spectrum for the same reasons. Most of this additional capacity has been on so-called Wi-Fi networks. Spectrum has been allocated to unlicensed use in the 900 MHz, 2.4 GHz and 5.2 GHz bands. In addition, new generations of technology have been introduced. From 802.11a and 802.11b in 1999 to 802.11g in 2003 to 802.11n in 2009 and future generations are under development.[10] The changes in technology have increased the carrying throughput of any Wi-Fi channel. Finally, and perhaps most importantly, the number of Wi-Fi networks has grown dramatically. One source reports more than 85 million Wi-Fi networks, although I suspect that is a lower bound as it only counts reported networks.[11] Because of the short-range nature of Wi-Fi transmissions, households adding a Wi-Fi network cover their homes and only at most a small number of nearby homes, meaning that the channels can be reused every few homes without substantial contention for the spectrum capacity.

II. Moving spectrum to be more flexibly allocated

Kwerel and Williams (1992) examine the benefits from reallocating television spectrum to general wireless service and find there would have been large benefits from such reallocation. They consider not only the Hatfield/Ax cost tradeoff, but also the net social surplus from the new services. One of the most important lessons from Kwerel and Williams (1992) and many other spectrum studies is that flexible use is a key to maximizing benefits from spectrum because flexibility allows spectrum users to provide more highly valued services.

Government regulates spectrum on several dimensions: flexible use vs. mandated use; licensed vs. open entry; primary and secondary usage rights; and technology choice. The government rules lead to very different outcomes in intensity of spectrum use (what engineers might call technical efficiency), and even more importantly, very different outcomes in the value of spectrum use.

Normally, market forces would push such imbalances away and cause the value of spectrum used for different services to move toward equality at the margin. As a matter of economics, without market power concerns, there should not be substantial

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[10] Negus and Petrick (2008)
[11] http://www.wigle.net/gps/gps/main/stats/

inefficiencies in the use of non-governmental spectrum where users face the full opportunity cost of spectrum use. Licensees with very flexible rights of usage and the ability to recover value from repurposing the use of the spectrum realize most if not all of the opportunity cost of their spectrum use, and act accordingly, with investment in capital and technological transitions, and would not "hoard" spectrum inefficiently.

There are at least three exceptions to the efficient use for non-governmental spectrum. First, when licenses restrict use, such as with television broadcasting and satellite and the licensees do not have flexibility in repurposing spectrum use. To achieve more efficient spectrum use, granting flexible usage rights should make a large improvement. At the same time, instituting fees on these users would be at best an indirect mechanism to correct for this government failure to design property rights flexibly.

Second, there are bands such as the 450-470 MHz private radio band where entry is open so that users do not have licenses that make them realize the full opportunity cost of their spectrum use. In these bands, spectrum coordinators work to accommodate all entrants to the band. As a result, if a single user adopts a more efficient technology for its use, the benefits redound to others: to new users who might be able to fit into the band and existing users who have a better chance of clear communications. With open entry, it is difficult to get user to adopt efficient technology without some other mechanism such as spectrum fees.

Third, sometimes there could be market power concerns. Rosston and Topper (2010) showed that market power was not a problem in the market for wireless services generally. But, it is important for the competition authorities to ensure that actions do not result in a reduction in competition that harms consumer welfare. FCC (2011) and DeGraba and Rosston (2013) show that the proposed AT&T – T-Mobile merger was likely to lead to higher prices, leading to the government action to block the merger and the ultimate abandonment of the deal by the parties.

For spectrum used by the government, there are two related margins on which to promote efficiency: allocating spectrum within government users; and allocating spectrum between the government and the market.

A. Government spectrum may be able to be used more efficiently

This section looks at how lack of flexibility, legacy technology, and lack of coordination impact the two main areas of spectrum users that most observers claim are inefficient: the federal government and commercial licensees without full flexibility and an ability to realize the opportunity cost of their use of spectrum.

The GAO reports that the Federal Government is the exclusive or predominant user of 39 to 57 percent of the spectrum between 225 MHz and 3.7 GHz. GAO (2012). In addition, state and local agencies have access to additional spectrum for public safety and other government responsibilities.

1. Incentives for efficient use by Government?

Government spectrum users do not generally face incentives to use spectrum efficiently. The government budget process makes it difficult for spectrum managers to have the correct incentives. It is critically important to provide sufficient resources to our agencies so that they can provide safety and security for the American public. For the vast majority of the tools used to provide safety and security, the government uses the market system. The government competes with private enterprise for soldiers, police, fire and all other employees. The government buys tanks, airplanes, bullets, computers, and food from commercial enterprises. The government also buys the radio equipment used with spectrum. But the government does not buy spectrum. Historically, it has been given the right to use certain blocks of spectrum, either exclusively or in conjunction with others.

If a government agency or spectrum manager has access to spectrum but does not have to pay for it or realize gains from vacating, it will have an incentive to keep access to this valuable resource for use now because it can reduce other operating costs, and also as an option for the future when it might be able to use the resource in a new service or use access in exchange with some other entity as the option value could be very valuable.

A government agency has no incentive to adopt equipment that would use half as much spectrum for the same mission unless it benefitted from releasing the remaining spectrum. When the cellular carriers invested in technology to move from AMPS to 2G to 3G and now from 3G to 4G, they see the benefits of this additional capacity because they can use the spectrum to provide more service. In contrast, a government agency with a narrow mission would see the cost of the new equipment, but not realize any benefit. In fact, the agency might lose even more because it loses the option value of converting to new equipment in the future that might continue to use the full block of spectrum, but provide additional necessary services. If the other portion of the spectrum were used by someone else, that option would be foreclosed.

Government agencies might be able to accept additional money from making spectrum available in auctions. However, because of the political budget process, I have argued that spectrum managers and even agency heads would be reluctant to believe that they would see any of the budget benefit in the long-run, much less the full value of the resource they gave up. Instead, if an agency released spectrum worth $10 billion, they might expect that over time, their budget would be reduced by an equivalent amount, with some possible increases to provide for replacement equipment, but by no means allowing the agency to reap the full benefit of the spectrum. (Rosston, 2001).

Whatever mechanisms are used to improve spectrum efficiency, they should take into account the importance of transitions from one use to another, including transaction costs and timing issues. Wireless networks require upfront design and investment. Hence a flash cut to a new mechanism could cause dislocation costs. As a result, any change should be announced well in advance and should be phased in gradually. Setting a process in place is also important to minimize subsequent opposition that would prevent ultimate use of the mechanisms at the time they are to be implemented. GAO (2012)

2. Improving the use of government spectrum

a) Fees

Charging annual fees for the use of the spectrum resource by government agencies has the potential to encourage agencies to realize the opportunity cost of the spectrum they use in a manner similar to the use of other market resources. Of course, it would be important to have a realistic measure of the opportunity cost or value of the spectrum right that is being used. The GAO manages rental prices for office buildings owned by the government and charges rent to different agencies in a similar manner. And buildings, even within specific city, just like different frequency bands, have very different market values and the GAO presumably charges different rental fees for internal government transfers.

Administered Incentive Pricing ("AIP") implementation in the UK provides some guidance for thinking about spectrum fees for government users. First, the goal should remain efficient use of spectrum, not to attempt simply to have users "give back" spectrum. The effectiveness of an AIP process cannot be measured by the amount of spectrum given back because changes in spectrum could be very small if the initial allocation is close to efficient or if changes take time to effectuate because of legacy system investment.

A second lesson from the UK is that once fees are set, it may be difficult to change them in the future. UK AIP fees were set at approximately 50% of the level that was thought to be appropriate. Instead of having a mechanism in place to increase the level to be more appropriate, the fees appear to be fixed at the lower level. As a result, only very inefficient government users would feel the incentive to stop paying the fees.[12]

There is some concern that spectrum fees would be too high and that government agencies would not be able to afford the spectrum they need to fulfill their missions. Setting fees above the market price would reduce government spectrum use too much, but if market-based fees were so high that the agencies could not afford the spectrum, that indicates that the mission costs are higher than the agencies believe and it is important to understand the true costs. It may take time for agencies to review their options and develop alternatives so it is important to publicize the fees well in advance of their implementation, provide certainty about the fee levels for a reasonable amount of time into the future (possible a rolling 5 –year window of future fees), and gradually introduce the fees, say 20% per year over 5 years. With these provisions, agencies can adjust their budgets to request additional funds for spectrum or implement alternatives to accomplish their missions. In this way, agencies will adjust their operations to reflect the value of the spectrum resources they use in accomplishing their missions.

[12] There may be some differences in systems using spectrum for the first time (new acquisitions of spectrum) and existing users of spectrum. It is important for new systems to immediately realize the full opportunity cost of their spectrum use because of the substantial sunk investment in new networks and equipment that may be long-lived. However, treating new systems and changes to existing systems differently will lead to incentives for agencies to maintain older inefficient systems if spectrum charges for older systems are substantially lower. As a result, it is important to have a clear time path for equalization of charges for new and existing systems.

At the same time, it is also possible for fees to have no effect if agencies simply request and receive additional funds earmarked for their spectrum needs. While budget increases are possible (and possibly likely in the very short term), over time, budget officers should see the true cost of using spectrum and better be able to understand the tradeoffs between spectrum use, capital investment and other techniques to accomplish missions. The downside risk of a fee system is small relative to the potential benefits of the system. Even if the fees had no effect, the transactions costs of determining and administering a set of fees is likely to be small relative to the value of spectrum at issue.

b) "Sharing"

Recently, there has been a large amount of discussion of "sharing" spectrum. Sharing can be mandated by rule or encouraged by fees like those discussed above. It is important to carefully determine a definition of sharing as the term "sharing" has come to mean different things to different people. Some people use the term to mean different end users transmitting on the same spectrum. Others use the term to imply that different systems can occupy the same spectrum. These two different visions can have very different implications for sharing rules and resulting efficiency.

Sharing is not an end in itself. Instead, the notion of sharing should be thought of in a context of increasing the value of the use of spectrum; sharing could increase the efficiency of spectrum use. If more people (with the same value) can use the same spectrum, then sharing is good. But "sharing" and "exclusive use" are not necessarily incompatible. Over 100 million users "share" the spectrum that is licensed to Verizon even though that spectrum is "exclusively" licensed to Verizon and not shared with any other licensee.

If Verizon realizes the opportunity cost of its spectrum use and had neither market power nor concerns about getting spectrum rights back in the future, it might allow other systems to use its spectrum if those users were willing to pay enough money to satisfy Verizon. But, Verizon may have a sufficiently high opportunity cost (which by an economist's definition would include any potential market power or plans for the introduction of new services) or there may be sufficient uncertainty about the resolution of interference or high transaction costs that Verizon would not negotiate with other providers to use its spectrum.

Government users face similar issues – they could share their spectrum with other users, but also face costs in such sharing, even if current missions would not be affected.

The PCAST report attempted to set forth a sharing framework for government spectrum, and the FCC added a possible implementation of this framework in its recent NPRM for the 3.5 GHz band.

The PCAST framework set forth a hierarchy of users: Primary, Secondary and Tertiary. Primary users would retain their transmission and protection rights. Secondary users could get priority access to the bands under certain conditions. For example, they might have guarantees of quality of service in certain areas or certain times, but need to protect the primary users. Tertiary users could operate under certain parameters, but must not degrade service to the primary and secondary users. In addition, tertiary users would have no claims against the primary and secondary users for degradation of tertiary users' service.

Many other variants could build from the PCAST framework. A government user might be willing to work with only a limited number of other users so that in the event of interference disputes, the government user would not have to deal with a large and diffuse set of users regarding determination of the source of interference and negotiation about the resolution of the issues. In other circumstances, a federal user might be willing to have a large number of low power users co-existing with it, but no relatively higher power single user so that there might only be a primary user with tertiary users and no secondary users.

Economics provides two rationales for advocating sharing on federal spectrum. First, as discussed above, federal users do not realize the opportunity cost of the spectrum they use. To the extent that sharing can increase the efficiency of the use of the spectrum to be closer to the socially optimal use, sharing would be beneficial. Of course, simply imposing sharing could lead to too little, too much, or the right amount of use of the bands. Without market prices for sharing, we would not know how much spectrum the government should use and how it should make sharing available.

Second, an important role of government is providing the public good of knowledge. To the extent that sharing techniques require experimentation, research and risk, the government may be in the best position to facilitate experiments in sharing that could then be adopted by private sector licensees who would benefit from the knowledge spillovers. For example, if the government can demonstrate that a technique for sharing, previously unknown, could allow two different technologies to share the spectrum, then commercial licensees might adopt similar techniques for sharing (either with other entities or virtual sharing within their own organizations to increase capacity). The private entities might not have sufficiently high incentives to invest in and develop the technologies on their own as they might not expect to be able to internalize enough of knowledge spillovers. However, because the commercial licensees with flexible use spectrum should realize the opportunity cost of their spectrum, they should not be forced to open their spectrum for sharing.

The Commerce Spectrum Management Advisory Committee (CSMAC) has been working to increase the efficiency of the use of spectrum held by the government.[13] It has produced reports on spectrum fees among other things. Currently, it is working to facilitate the shared use of the 1755- 1850 MHz bands. By drawing attention to the potential value of these frequencies in commercial use, the CSMAC has pushed the government to try to facilitate sharing with commercial entities. However, it is not clear how much success it will have nor whether its goals are too high or sufficiently high for transferring rights to the private sector.

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[13] The Commerce Spectrum Management Advisory Committee (CSMAC) advises the Assistant Secretary for Communications and Information at NTIA on a broad range of spectrum policy issues.

B. Broadcast spectrum

The FCC allocated over 400 MHz in the VHF and UHF bands for over the air broadcast television in the 1940s (Hazlett, 2008). It allocated, and has continued to allocate, this spectrum specifically for free over the air broadcast television on a site-specific basis. While broadcasters can provide ancillary services for a fee, the FCC rules do not allow the broadcasters to terminate broadcasting and provide other services instead. In addition, the FCC is effectively the licensee for all of the areas not covered by site-specific licenses. Because of these constraints, the broadcasters do not realize the full opportunity cost of their use of the spectrum.

In 1970, the FCC reallocated channels 70 - 83 (14 channels) to land mobile radio, including cellular and private radio.[14] In addition, in certain areas, the FCC allowed public safety users to make use of spectrum occupied by channels 14 – 20.[15] The FCC began its transition to digital television by giving broadcasters a second "digital" channel on a temporary basis, and then in 2009, terminating analog broadcasting, freeing up a large number of channels. Prior to the termination of the analog broadcasts, the FCC auctioned the rights for channels 51 – 69 to be used flexibly.

As a result of these actions, a substantial amount of broadcast spectrum has been transitioned from a specific use (which may have been socially optimal at some point in time) to flexible use that can more easily evolve over time as technology and demand change.

To date, these reallocations have not required any broadcaster with a full license to cease broadcasting – the FCC has been able to find vacant channels for broadcasters that had been transmitting on the reallocated channels. Such "free" transitions are much less likely to occur since the digital transition packed the channels more tightly and reallocated much of the vacant spectrum.

C. Other underutilized spectrum

In addition to the government spectrum and the television broadcast spectrum, the FCC should make more capacity available to the market by reducing restrictions on spectrum use. In most cases, it made mistakes by limiting flexibility at initial licensing and not completely allocating the rights with the spectrum. The FCC can rectify this problem by increasing flexibility and comprehensively allocating transmission rights. For example, the FCC has begun to allow terrestrial use of spectrum that it had initially restricted to satellite use only. This move highlights two issues that result from inefficient spectrum restrictions and a lack of clear enforcement of rights.

In 1997, the FCC auctioned 30 MHz of spectrum for "Wireless Communication Services" ("WCS"). The WCS spectrum is next to the spectrum that the FCC allocated specifically for Digital Audio Radio Service ("DARS") XM Radio and Sirius Radio were the two purchasers of the DARS license at the FCC auction. Because of its desire to promote DARS, the FCC put extremely stringent interference requirements on WCS that

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[14] Federal Communications Commission (1970).
[15] Federal Communications Commission (1973).

essentially rendered the spectrum useless for mobile, and even for most fixed applications. Had the FCC instead auctioned the two bands together with a possible package bid, then the DARS providers could have expressed the value of their service compared to the value that terrestrial wireless providers would have placed on being able to transmit at higher power.

As it stands, the WCS spectrum has essentially remained fallow for 15 years and is only now possibly becoming usable because of recent FCC rule changes. With a more flexible allocation for both WCS and DARS spectrum together, the FCC could have auctioned the initial spectrum rights and let the marketplace determine the highest value use of the spectrum. Given the merger of the two DARS licensees, it is highly likely that the FCC allocated too much spectrum for DARS and could have engendered more consumer value by enabling higher power use on the WCS portion of the band. The FCC's faulty initial conditions (including requirements to launch and operate satellites) made transitions much more difficult than they should have been.

The recent case of LightSquared is another example of where the lack of clarity of initial rights and subsequent enforcement of rights led to spectrum being unused. LightSquared claims that it would be operating within its rights, but that adjacent GPS receivers have been poorly designed (to save on costs) while the adjacent spectrum was idle and planned to be used in satellite-only service. The low cost GPS design apparently means that even if LightSquared operates in compliance with the terrestrial operating restrictions of its license, it would cause interference to the GPS devices.

Some argue that this is a problem with property rights and flexibility (Feld, 2011). Instead, it shows that lack of clarity about emission rights, lack of enforcement, and inefficient restrictions on flexibility can cause incentives to use the political process to lock in place rights that were not there before. A better solution would be to allocate rights more broadly and clearly. Instead of allocating rights for satellite service, the FCC should allow satellite and terrestrial with initial emission rights and protection from interference that can then be negotiated with other licensees. The FCC appears to be moving more toward flexible use – the recent decision to allow DISH network to use the spectrum licenses for terrestrial service removes some inefficient restriction on use.[16]

D. Flexible use

The goal, from an economic perspective, should be flexible use spectrum.[17] Essentially, this means licensees should have technological flexibility, and service flexibility.[18]

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[16] Some may argue that there is "unjust enrichment" because Dish (and it predecessor licensees) acquired the licenses under the rules that restricted their use.

[17] There may be some beneficial restrictions on use for initial transmission and interference parameters. For example, it may make sense to group low power transmitters in similar bands and not have them adjacent to high power transmitters. However, if there are sufficiently well-laid out license rights, the license holders should be in a position to negotiate changes to those rights.

[18] For a fuller discussion, see Rosston and Steinberg (1997).

Technological flexibility means that licensees can decide to change the nature of their transmissions. Subject to the interference parameters of their licenses (as modified through negotiations), parties should be able to implement the technology of their choosing. For example, AT&T has changed the transmission on its frequencies from AMPS to TDMA to GSM to EDGE to HSPA in less than 20 years without getting FCC approval in advance for its business decisions, with the exception that the FCC mandated the continuation of AMPS past the efficient transition period. AT&T made these changes to increase capacity and the quality of its network and consumers benefit from the increased capacity and quality. Had it been required to obtain pre-approval from the FCC, the transitions likely would have taken longer, like the transition away from AMPS, and may not have been as competitively significant.

However, there should be limits on what a licensee should be allowed to do technologically– for example, it could not change its transmission so that it encroached on other licensees, either geographically with co-channel licensees, or in frequency to harm adjacent (or other) licensees. There is a large caveat to this restriction – if the licensee is able to negotiate with its "neighbors" so that it can change its transmission, it should be allowed to do so.

In terms of service provision, the FCC has put restrictions on certain licenses. Broadcasters must provide free over the air television service. Certain other licenses have similar service restrictions. Generally, with a competitive spectrum market, the FCC should abolish all service restrictions so that spectrum can be used to provide the highest value services.

E. Cost of relocation/sharing

Because the FCC has put different systems in different regulatory categories, one of the costs of reallocating spectrum is the cost of "relocating" existing systems. Had there been complete flexibility, the licensees would internalize these costs. However, there are costs for relocating (or shutting down) private licensees and also for transitioning government systems.

Historically, the FCC simply told licensees to vacate spectrum. For example, television stations in channels 70-83 were allowed to get different channels or to go off the air when the FCC reallocated that spectrum for land mobile radio use. Starting with the PCS auctions in 1994, the FCC moved to a more efficient relocation mechanism whereby the new spectrum users would not only pay for the spectrum rights but would also have to take into account the cost of relocating the incumbent users. (Cramton et al, 1998).

In the case of PCS, the spectrum incumbents were point-to-point microwave users. The PCS winners were able to negotiate with the incumbents and pay for them to vacate the PCS band. Some incumbents obtained point-to-licenses in other bands, some switched to other communication means (from commercial providers or using wired solutions) and others reduced their use of the communications path.

The expected cost of the relocation should have been considered in the bids for the spectrum licenses. In other auctions, there may be provisions where the auction proceeds are used to pay the relocation costs rather than having negotiations between auction winners and incumbents. In either case the net revenue to the government for the relocation should be similar (depending on how the negotiation rules change) whether the costs are paid by the winners directly or through the auction revenues. Bidders should look at the net cost of the additional spectrum.

If the value to a new user is higher than the cost necessary to keep an incumbent equally well off, then it would be efficient to reallocate the spectrum to the new user (and use). If the new users are not willing to pay enough, then the transfer is not efficient. However, it may be the case that at different points in time, depending on the expected future streams of revenue and cost for the incumbent, that transfers may be more or less desirable. For example, an incumbent that sees that it would have put in a new system in two years might be more willing to vacate to avoid the capital expense than an incumbent with a system that has an expected life of 20 years.

Currently, the FCC is investigating reallocating more spectrum from specific-use broadcast to flexible use. The FCC has a Notice of Proposed Rule Making for so-called "incentive auctions" that area designed to allow broadcasters to state their willingness to accept payment for going off the air or switching to a different television band (FCC, 2012).

In conjunction with the determination of the willingness of broadcasters to vacate spectrum (the supply side of the market combined with currently vacant channels), the auctions will also determine the willingness to pay of wireless providers for the vacated spectrum (the demand side of the market). If there is sufficient willingness to pay, then some broadcasters will cease broadcasting and vacate the spectrum and it will be reallocated for flexible use.[19]

These "incentive" auctions are complex and may take years to implement. However, they provide the possibility of up to 120 MHz of prime spectrum for flexible wireless use. While this auction does not grant flexibility for the broadcasters, it is a mechanism to allow them to realize some or all of the opportunity cost of their television broadcasts.

The social cost of such a transition may not be high as the vast majority of television viewers do not use the over-the-air broadcasts and hence the termination of such broadcasts would only affect a relatively small number of households. Even then, there will likely be a number of remaining over-the-air broadcasters, which presumably would be those with the highest value to over-the-air households, so that would minimize any losses from the transition.

[19] One additional feature of the auctions are that not only does there have to be sufficient money to pay the broadcasters to vacate the spectrum, but there also needs to be enough to fund a public safety wireless network, on the order of $8b.

III. Role of licensed and unlicensed spectrum.

The discussion to this point has used examples from licensed spectrum to illustrate the value of flexibility. Flexibility is also important for unlicensed spectrum use. Indeed, it is flexibility that has led to many of the innovations in service and capacity now available on unlicensed networks. The use of unlicensed spectrum has created great value for users and much of the value emanates from the flexibility of equipment designers to change the services they provide without difficulty.

However, unlicensed spectrum works with certain requirements that help prevent inefficient overuse or contention with the unlicensed bands, but can also limit flexibility for unlicensed users. Such flexibility limitations can be overall beneficial as it ensures that other users are able to operate without being subject to undue service degradation from an overly high power system. However, changing the rules once in place with a large diverse group of users can be difficult in certain circumstances.

A. How much unlicensed spectrum should there be?

The theory behind unlicensed operation is that each user does not cause any, or only causes minimal contention for the use of the spectrum. With only minimal contention for the use of spectrum, the etiquettes and protocols can be fairly unobtrusive and have minimal effect on users. For example, my use of Wi-Fi affects my next-door neighbors on either side, but not the houses on the other sides of them. Because of power limits, the signal travels (reasonably) well in our house, but not two houses away. In that way, they can use the Wi-Fi as much as they want and not cause any direct contention for my use.

Low-power unlicensed use causes little contention within the band. However, there is contention when a band is exclusively designated for unlicensed. Such a designation means that the band cannot be used for licensed use. That means that unlicensed use, even if each individual use does not cause contention, overall causes contention with licensed use and creates an opportunity cost.

Milgrom et al (2011) argue that there is a potentially very high value for unlicensed use, and that such use might not decrease auction proceeds for licensed spectrum because unlicensed use can serve as a complement to licensed spectrum, increasing the value of the licensed spectrum that is auction. They are correct in both statements.

However it is hard to determine the quantity of spectrum that should be dedicated to unlicensed use. While Milgrom et al (2011) argue that bidders might undervalue the unlicensed spectrum, they do not provide any guidance or assurance that regulators would be better at determining the amount of unlicensed spectrum.

There are some ways in which one might at least make some rough judgments about how much unlicensed spectrum to allocate. Instead of simply allocating a band of spectrum for unlicensed use, the FCC could allow bidders to express a preference for licensed use by bidding on it. In this auction, the FCC could set a reserve price, essentially declaring the social value of unlicensed use equal to the reserve price and seeing if the value of the spectrum in licensed use is higher. It is difficult to pick a level for the reserve price, but by simply declaring that spectrum will be unlicensed, the FCC is essentially setting a reserve price at an infinite level when it allocates unlicensed spectrum. With a set-aside rather than an explicit reserve price, the FCC hides the forgone revenue and opportunity cost of using the unlicensed spectrum.

The FCC might also use the auction format in other ways to see if bidders would have different valuations for the licensed spectrum if there were a nearby unlicensed band than were that band allocated to additional licensed use. The ability to have bidders submit multiple bids for different "packages" of "licensed only" and "licensed + unlicensed" would allow the FCC to understand at least the differential valuations of bidders. At the same time, equipment manufacturers and other companies that support the provision of unlicensed spectrum could participate in an auction with bids to support unlicensed use.

It is important for regulators to realize when making allocation decisions that both licensed and unlicensed spectrum have high potential value and to understand how the two work together and not simply to assess one with a high value and assume that we need more of it. Instead, it is important to understand the marginal valuations of additional spectrum.

B. What characteristics are better with unlicensed?

In order to think about the amount and type of spectrum to use for unlicensed spectrum, it is useful to think about the economic characteristics that make unlicensed spectrum valuable.

The protocols and available spectrum mean that transmission distances for unlicensed uses are measured in feet. While some systems have used unlicensed spectrum to cover areas large relative to a home Wi-Fi system (eg. Tropos, Google, Comcast), those metro mesh networks tend to be small in comparison to the coverage of commercial cellular systems. In addition, the metro Wi-Fi systems operate with the unlicensed protocols and each transmission is for a small area even though multiple transmissions are put together as in a typical licensed cellular system to cover an area. The use of the unlicensed spectrum by mesh networks can therefore cause contention to other small Wi-Fi networks in the same area.

At the same time that there are "macro" metro Wi-Fi systems, licensed systems are moving to smaller and smaller cells with the addition of femto cells and Distributed Antenna Systems ("DAS"). Smaller cells allow licensed systems to increase capacity substantially and also to look more like the very limited range of unlicensed. In addition, licensed systems are incorporating Wi-Fi systems to offload data to reduce the traffic on their networks.

If the FCC increases the amount of spectrum for unlicensed use, contention should only increase from what would happen without the extra spectrum if the extra spectrum causes higher quality service that in turn increases demand substantially. However, if the FCC allows higher power, then one of the main benefits of unlicensed spectrum use, the lack of contention, could disappear. Chairman Genachowski (2012) recently lamented the slow speeds of Wi-Fi in crowded airports because of the relatively large number of devices trying to share the same fixed amount of unlicensed spectrum, "As innovation opportunities and demand for unlicensed uses continue to grow, and Wi-Fi networks get more and more congested – have you tried using Wi-Fi in a busy airport recently?"[20]

The concentrations of unlicensed use in a single small area show one of the key economic drawbacks of unlicensed spectrum, "unlicensed spectrum is shared between many users and devices, and therefore may suffer from congestion and interference" (Milgrom et al, 2011, p-21). Expanding the range of unlicensed spectrum offers the opportunity for greater unlicensed coverage. However, expanding the range of transmissions is equivalent to crowding more transmissions into the airport and hence increases congestion and interference.

While there are protocols and etiquettes for usage, such mechanisms do not necessarily lead to efficient usage. No one can express a high willingness to pay for use of the spectrum so that low value and high value uses have the same priority. Essentially, as transmission distances increase, the amount of contention caused within unlicensed use increases and the economic argument for unlicensed use decreases. Economically, unlicensed use is appropriate when there is little or no within band contention and no economically reasonable use charge, but as contention grows, the economically appropriate use charge rises above zero and licensed spectrum becomes more appropriate.

It is important to ensure that this is not an argument to reduce the power of unlicensed transmissions on low frequency bands so that there is no contention. Bands should be used optimally and not set up in a manner to fit a certain profile to get favorable regulatory treatment. In addition, it is important to ensure that there is competition for licensed spectrum systems. However, using unlicensed spectrum in low frequency bands where contention within unlicensed use is likely to be greatest is likely to be an inefficient use of the spectrum resource.

C. Licensing regimes

There are a variety of different regimes within licensed and unlicensed use of spectrum. At one extreme would be exclusive licensed whereby the licensee has all rights for transmission in a specific band. Exclusive licenses could be for a geographic area such as an MTA, or could be for a fixed point-to-point path. A second type of licensing regime involves non-exclusive licensing. In one case a primary licensee has the right to operate without interference from other users, but other users are allowed to operate. The "secondary" users in this case would also be licensed, but would be restricted from harming the primary licensees operation and would have to deal with potential harm from the primary licensees emissions. In a variant of this, it is possible to have "secondary" users not need licenses, but be able to operate in the same fashion – not causing harm and accepting harm. The next level would be non-exclusive licenses. In the private radio bands, users require licenses, but anyone qualified is able to get a license. The private radio coordinators add the new user and there could be some degradation in the quality of service for the pre-existing users. Finally, there are open entry bands without licenses

[20] It is unclear if there is substantial contention in the current unlicensed bands. If not, it may not be useful to increase allocations of spectrum for unlicensed use.

that have typically been referred to as unlicensed bands. Typically such bands have regulation on the operating characteristics of the transmitters to manage the contention for the spectrum.

The table below shows some of the tradeoffs from the different licensing possibilities.

	Benefits	**Costs**
Exclusive Primary Only	Licensees bear the opportunity cost of unused or underutilized spectrum. Licensees have the ability to coordinate use in the band and to internalize contention in the band. Incentive to invest in the band for the long term and upgrade to new technology.	Transactions costs may make it uneconomic for others to negotiate deals for unused or underutilized spectrum. Market power may provide incentives to prevent others from using the spectrum to provide service.
Open Entry Licensed	Low cost of entry.	Unlimited entry can cause contention. Users may acquire more resources than needed so when have to share, get what they need. Hard to facilitate efficient spectrum use and migration to new technology.
Primary and Secondary Licensed	Primary licensee has similar incentives to exclusive use. Secondary licensee can make use of unused or underused spectrum. If there is harm from operation, easy to assess source of harm.	Potentially hard for primary licensee to assert rights if it wants to use or change its use of spectrum and that subjects it or the secondary licensee to harm. Hard to evict secondary users.
Primary Licensed and Secondary Unlicensed	Primary licensee has similar incentives to exclusive use. Secondary user can make use of unused or underused spectrum.	Potentially hard for primary licensee to assert rights if it wants to use or change its use of spectrum and that subjects the secondary users to harm. Hard to evict secondary users. If there is harm from operation, potentially hard to assess source of harm and enforce usage rights.
Open Entry Unlicensed	Easy entry for users. May allow for rapid introduction of new technology. Limited concerns about exercise of market power.	Required to set operating metrics in advance and may make transition to more efficient technology lengthy. Precludes use by exclusive licensee. Can create contention.

IV. Conclusion

Spectrum policy is very important for the continued growth and pricing of wireless services. The quality and cost of licensed and unlicensed services depend on the availability of spectrum and on the rules for the use of spectrum set by the FCC and by NTIA. History shows that setting initial flexible rules allows users to realize the opportunity cost of their spectrum usage, leading to investments in technology and much more efficient transitions of use. When users do not realize fully the opportunity cost of their spectrum use, either due to license restrictions, or due to being a government entity with limited ability to benefit from more efficient use, spectrum tends to be used sub-optimally.

Incentives for economically efficient spectrum use have proven effective and the use of fees and market prices for sharing could lead to an increased effective supply of spectrum to meet the growing demand for spectrum.

There is a role for both licensed and unlicensed spectrum. Unlicensed spectrum can be both a complement to and substitute for licensed spectrum in use. In both roles, it serves a valuable social purpose. But, allocating spectrum for unlicensed use imposes an opportunity cost – the spectrum cannot be used for licensed use. As a result, it makes sense to allocate spectrum for unlicensed use where the propagation characteristics are amenable to the key feature of unlicensed use – limited contention. In addition, the FCC should attempt to understand the magnitude of the opportunity cost of allocating spectrum for unlicensed use.

Overall, there is a large opportunity for the government to increase wireless capacity through technology, spectrum and incentives.

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