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Seven Key Options for Spectrum Allocation and Assignment

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In a February 2010 speech previewing the Federal Communications Commission (FCC) spectrum plans for the National Broadband Plan, Chairman Genachowski described spectrum as "the oxygen of mobile broadband."[1] During the speech the Chairman introduced a key goal of FCC's National Broadband Plan "freeing up to 500 Megahertz of spectrum over the next decade."[2] The Plan focuses extensively on the issue of spectrum for increasing broadband access. It is seen not only as key to promoting continued innovation in mobile broadband, but also underpins the FCC's strategy for increasing competition in the broader market for broadband access – where it expects mobile broadband to serve as a close competitor to lower speed fixed broadband services.[3]

Much of the discussion in the press and at the FCC thus far regarding spectrum and the National Broadband Plan has centered on the goal of re-claiming 120 MHz of the frequency band currently utilized by over-the-air broadcasters. In exchange for a percentage of auction proceeds, broadcasters could voluntarily agree to go off the air or agree to share a channel with another broadcaster.[4] Proposals to also free up underutilized spectrum currently assigned to federal government users for auction are also at the top of the FCC's agenda for implementing the Plan.[5] In both of these contexts, the overriding policy focus is on clearing incumbent and often inefficient users of spectrum for the purpose of auctioning to the highest bidder.

Over the past two decades, the reliance on spectrum auctions to allocate spectrum has grown substantially.[6] Auctions have been theorized to be a fairer, more efficient and more transparent method for assigning frequencies among contending parties and interests. They also have been favored for their ability to generate substantial short-term revenues for the U.S. treasury.[7] However, recent spectrum auctions have also demonstrated severe limitations in terms of promoting competition and ensuring access to valuable frequencies for smaller firms, local communities, non-profit organizations, public interest groups, and civil society NGOs. Even with flexible-use licenses, auctions are inherently biased towards specific spectrum uses and users. Moreover, the value of spectrum sold to the highest bidder reflects the highest economic value at the time of the auction, while failing to account for the future, and often much higher value of the resource.

As the FCC looks to meet the concomitant goals of allocating 300 MHz of newly available spectrum for "mobile flexible use" by 2015, 500 MHz by 2020, as well as address the nation's long term spectrum needs, the FCC will find it extremely difficult to achieve those goals only through a 'clear and auction' strategy.[8] The spectrum allocation process does not exist in a vacuum and "today's spectrum incumbents—including broadcasters and the government itself—use their political clout to stifle competition by keeping a firm chokehold on large swaths of spectrum that could be put to more efficient uses."[9] As is often the case, technology has outpaced regulation and new thinking is needed to take advantage of innovations that will reduce scarcity and dramatically increase spectrum access and efficient use.[10] This impending paradigm shift in spectrum use will require policymakers to utilize a broad set of spectrum allocation options to both meet increasing demand for spectrum access and promote continued innovation.

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The Rise of the Spectrum Auction

The 1927 Radio Act allowed for "the use of such [radio] channels, but not the ownership there of."[11] This "nonownership" clause was seamlessly transferred into the 1934 Communications Act.[12] These acts clearly established the foundation for licensure rather than exclusive private ownership of the airwaves. Ronald Coase, in his seminal 1959 article, "The Federal Communications Commission,"[13] characterized the precursor 1927 Radio Act as a missed opportunity for asserting a property rights regime of spectrum management in which market operations would dictate allocations.[14] The article, which helped launch an intellectual movement in support of spectrum privatization, lamented the fact that these early laws codified the public interest doctrine and established the spectrum as public property, albeit under federal oversight and management.

According to the "Coase Theorem," spectrum policy based on public interest grounds was fundamentally flawed and a private property regime would allow the free market to allocate resources to their most efficient use—assuming that transaction costs are kept low. Coase argues, "since it is generally agreed that the use of private property and the pricing system is in the public interest in other fields, why should it not also be in broadcasting?"[15] Coase's market-based approach was later adapted to fit a licensure model, falling short of treating spectrum as private property and instead replacing the comparative hearings model with allocating spectrum to the highest bidder via auctions—a practice that became increasingly standard in the 1990s under the Clinton administration. Other market-oriented reforms dictated that personal communication services and secondary markets were operated in ways that treated spectrum as a private good. The past few years have witnessed a renewed call for further privatization of spectrum.[16]

The private property approach to spectrum management generally views the market as a neutral if not benevolent arbiter. However, policymakers often ignore the approach's inherent biases towards the monetization of "public interests" and externalization of benefits that cannot be commoditized. Critics see this approach as disproportionately benefiting powerful economic interests and privileging profit-making uses, especially given the prohibitive upfront costs for purchasing exclusive rights to spectrum. In light of this bias, policy historians David Moss and Michel Fein provide a critique of Coase's assumption arguing that the driving concern behind the 1927 Radio Act was primarily technical and economic.[17] Moss and Fein demonstrate that officials were less concerned about devising an economically efficient means of allocating scarce spectrum and more concerned with preventing monopoly markets and the concentration of political power. The decision by U.S. regulators to license radio and television stations on a local basis, rather than regionally or nationally like other nations, further underscores the desire to limit monopolies as well as to encourage local use of the public airwaves. By privileging democratic principles over economic concerns, a number of government officials involved in these policy debates aimed to create a diversity of voices on the airwaves and maximize social welfare. Nevertheless, such normative concerns have been largely stripped from the property rights model of spectrum management.

Broadening Our Spectrum Thinking

A singular focus on one-off auctions does not fully take into account the trade-off between maximizing short-term revenues and addressing other policy goals such a promoting competition, addressing the digital divide, and encouraging new, innovative uses and technologies. Since pioneering the use of spectrum auctions as the dominant paradigm for frequency assignment, the U.S. has seen diversity and competition suffer greatly, with the levels of independent carriers and minority and women-owned spectrum licenses plummeting and spectrum consolidation increasing.[18] The high price of spectrum at auction only furthers the incentive for commercial users of spectrum to prioritize higher revenue customers and delay coverage to less densely populated areas.[19] Moreover, given an auction's reliance upon monetary bidding as a sole determinant for awarding spectrum licenses, even a model auction may fail to maximize the social and economic benefits derived from spectrum access to all possible users, especially given the difficulty of estimating potential consumer and societal benefits from new business models and technologies that are being developed.[20]

The point of the above critique is not to dismiss auctions as a viable or appropriate allocation mechanism, but to suggest that spectrum allocation decisions should act in concert with public policy goals; allowing regulators to explore and utilize a broad range of solutions to meet those goals. To ensure that spectrum allocation decisions and assignments as a whole are fair and maximize the public benefit, it is critically important to look beyond auctions as a sole solution. Telecommunications regulators and policymakers have a responsibility as stewards of the public airwaves to examine both efficient and equitable outcomes in an effort to maximize social welfare and ensure that all sectors within a democratic society have access.

In this paper we propose and examine seven key options for spectrum allocation that the FCC should consider:

1. Traditional auctions: one-time payments from the highest bidder for the exclusive use of a particular frequency.
2. Annual and revenue-sharing fees: recurring (e.g., yearly) payments for the exclusive use of specific frequencies.
3. Micropayments and real-time auctions: "pay-for-play" for the use of specific frequencies at a specific time.
4. Lite licensing: requirement to license a transmitter, but providing no primary or exclusive use of a frequency.
5. Primary and secondary shared use: allow high power and low power uses to co-exist on the same frequencies.
6. Unlicensed: opening a specific frequency to all devices that meet a specific set of technical specifications and requiring no licensing of these transmitters.
7. Opportunistic (re)use: Allowing devices to opportunistically identify unused frequencies and transmit on those frequencies.

This paper explores each of these options and provides: criteria for ensuring fairness and transparency; strengths and weaknesses for each option; the key opportunities for spectrum usage that each approach facilitates; and, real-word exemplars from around the globe. The additional options to traditional auctions take advantage of technological innovations over the past several decades, facilitating lower barriers to entry for new providers and end users, encouraging greater innovation and potentially increasing revenues for the public treasury. Different spectrum assignment options will prove optimal depending upon the unique characteristics and desired uses for various spectrum bands; however, all are needed to maximize both the public and economic benefit from spectrum resources.

Seven Key Options for Spectrum Allocation and Assignment

1. Traditional auctions: one-time fees from the highest bidder for the exclusive use of a particular band.[21]

Auctions have been theorized to an efficient mechanism for allocating spectrum. But often auctions are driven by the goal of revenue maximization, even though such a focus often results in poor communications policy.[22] As Peter Cramton contends the "goal for the government should be efficiency, not revenue maximization." The latter is likely to encourage the creation of monopolies "which would create the highest profits before spectrum fees, and therefore would sustain the largest fees."[23] In the long-run facilitating competition will "lead to greater innovation and better and cheaper services and will likely generate *greater* government revenues."[24]

Policymakers should recognize that new entrants face two substantial hurdles; the fixed cost of building a network and the vested interest incumbent providers have in preventing the entry of new players.[25] As a consequence, auctions must be designed to factor in policy goals such as facilitating competition or increasing access in un-served or underserved areas. Designs should reflect the market realities and allow for conditions that will move toward policy goals – even if they do not maximize short-term revenues. The statute providing authority for the FCC to organize spectrum auction, does not specify the extent to which auction revenues should direct federal spectrum policy, only instructing the FCC to "pursue the public interest" and forbidding them from "merely equating the public interest with auction revenue."[26]

The FCC has placed conditions and limitations on its past auctions to facilitate competition. It successfully utilized spectrum caps in the 1994 PCS auction.[27] In the auction of the 700 MHz C block the winning bidder was subject to open device requirements – although it is unclear the extent to which the FCC will enforce those requirements.[28] Other past efforts to utilize set-asides, bidding credits, and installment payments to increase the number of new entrants have also yielded mixed results.[29] Even so, given the increasing dominance of a small number of firms in recent auctions, the FCC must continue to look for means to facilitate competition and entry within the auction model.[30] It should continue to refine and learn from other successful efforts around the world such a Canada's use of set-asides in its 2008 AWS auction[31] or the UK government's inclusion of roaming mandates on incumbents as a condition of winning a license in its 3G auction.[32]

Ensuring Fairness and Transparency
Spectrum auction must be fair and transparent. The preconditions to an auction (e.g., eligibility criteria, timelines for getting ready for an auction), the auction process itself, and follow-ups to

the auction (e.g., implementation of public interest obligations, deployment/build-out schedules, vacancy of bands auctioned) should be held to the highest standards.[33] However, the challenge of creating fair and transparent auctions must be acknowledged. As former FCC Chief Economist, Simon Wilkie noted, "spectrum allocation does not happen in a vacuum. Various incumbent players in the sector... have strong incentives to influence this process to their benefit."[34] This is particularly true for the regulatory process to determine the auction design and rules; which can be prone to the very same rent-seeking behavior that auctions were intended to combat.[35]

Strengths

1. Provides an "objective" method for assigning spectrum frequencies.
2. With proper safeguards, creates a transparent process for determining spectrum allocation and/or assignment.
3. Allows for the build-out of large (regional, national, and international) networks and facilitates the creation of new markets and consumer services.

Weaknesses

1. Limits competition, local access and marginalizes constituencies who lack the necessary capital reserves to purchase spectrum rights.
2. Allows for "spectrum warehousing" and "spectrum flipping."[36]
3. Measures the exchange value of spectrum but ignores social and economic benefits that are not commodified by the license bidder nor the value of the resource to consumers.[37]

Optimal Spectrum Uses

1. Cellular telephone networks.
2. Broadcast services.
3. Allocating scarce spectrum assets within a short amount of time among multiple competitors.

Real-World Exemplars

1. Most cellular telephone networks.
2. Satellite-based services.
3. Advanced Wireless Services (AWS), LTE, and 4G.

2. Annual and revenue-sharing fees: recurring (e.g., yearly) payments for the exclusive use of specific frequencies.

Rather than potential licensee bidding in terms of a one-time payment, they can bid in terms of an annual fee to lease the spectrum. Although auctions may offer a higher, immediate influx of revenues in return for an exclusive license, annual spectrum fees can provide the opportunity for perpetual income for the government. They also can encourage more entry by reducing the capital needed initially to acquire a license.[38] More importantly, they create an opportunity cost for the licensee to assist in aligning incentives away from spectrum warehousing or underutilization, to more efficient utilization of spectrum and secondary market transactions.[39] There is currently almost no option for systematically re-purposing underutilized spectrum. Once a license is granted, it is extremely difficult for the government to reallocate that band, even if it is underutilized or not used at all. Although, a licensee may choose to ignore less profitable rural areas, an efficient spectrum fees could induce the licensee to lease spectrum firms willing to serve those areas, rather than leave the spectrum idle.[40] Properly designed spectrum fees could also accelerate the build-out of services, while providing firms the flexibility to make appropriate business decisions.[41]

A variation on the annual spectrum fee is revenue sharing. In 1999, India moved from an allocation approach that required an upfront payment for the spectrum and a fixed annual fee to a fee structure where the licensee makes a one-time payment as license price and then pays a percentage of their revenue as the annual fee. The former appeared to lead to a low-service rollout as result of high annual fees, prompting the government to change its policy.[42] Under the new framework, licensees would bid on the entry fee and pay a license fee as percentage of revenue to the Indian government.[43] An analysis by Karan, Saurabh, Kaur, Satyarth, and Chintan investigated India's decision to utilize the revenue sharing model concluded that "fixed license fees [were] in no way superior to a revenue based license fee."[44] Moreover revenue sharing appeared to have "some impact on easing the entry barriers and stimulating competition."[45]

The revenue sharing model does include some additional risks when compared to auctions. Revenue sharing allows the general public to share in the proceeds that license holders generate from the use of the public airwaves; but also places the government with the potential risk of not receiving any funding if a license holder fails to prosper. This risk can be alleviated somewhat through the use of minimum yearly license fees. Moreover, revenue sharing requires a robust enforcement mechanism to ensure licensees are not underreporting revenues.[46] Several economists have argued that yearly fees would induce corporations to provide services in fewer areas and/or to maximize users on existing licenses (i.e., boosting congestion on wireless networks). Since identical market forces exist with auctioned licenses, similar solutions can be implemented including mandated build-out, limitations on contention ratios, and specific coverage requirements.

Ensuring Fairness and Transparency

Ensuring fairness for spectrum fee and revenue-sharing can be relatively straight-forward. For example, if competition for licenses within a certain class or allocation is minimal, then fee amounts should be similar. Where adequate competition exists, revenue-sharing auctions can be undertaken to decide who will receive an allocation. If regulators decide that they wish to raise revenue-sharing fees, this should be done at a predetermined time and within preset guidelines in order to minimize potential disruptions to existing business models. Likewise, all licenses within a certain class of services (e.g., wireless telephone, broadband) should face similar timelines and guidelines (as mediated by auction-based arrangements).

Strengths

1. Allows organizations to compete for frequency assignments that do not have substantial capital reserves to pay upfront for spectrum rights.
2. Facilitates the re-purposing of underutilized or unused spectrum.
3. Provides an ongoing income source to a federal treasury that will often provide substantially more income over time than the one-time revenue from traditional auctions.

Weaknesses

1. Shared risk (i.e., if the company fails to generate revenue, payments to the government may be minimal or non-existent if minimum payment amounts are not set).
2. Some economists state that introducing yearly revenue-based fees would lead corporations to provide fewer or more limited services.
3. May encourage non-interoperable networks and technologies.

Optimal Spectrum Uses

1. Licensed uses requiring continued public support to maximize their utility to the general populace (e.g., BBC in the UK).[47]
2. Services where regulators desire to mandate universal service requirements (e.g., telephone, broadband).
3. Allocations where long-term revenue-sharing generates more income than would be expected from one-time sales (e.g., technologies that are expected to have a high growth and uptake rate).

Real-World Exemplars

1. This is a de-facto reality in the U.K. where television users pay a yearly fee to the government and this funding is used to support programs like the BBC.
2. M2Z networks, proposed a revenue-sharing model in return for its exclusive use of the 2155-2175 MHz spectrum in the U.S.
3. Today, multiple countries around the globe utilize some form of revenue-sharing model.

Country	Annual non Spectrum Related Fees	Fee Type	License Types
Austria	0.1 – 0.2 % of gross turnover	Revenue sharing	All licenses
Chile	Variable fixed fees	Annual licensing fee	All licenses
Croatia	USD 6.6M	Annual licensing fee	3G Mobile*
France	1% of 3G revenues	Revenue sharing	3G Mobile
Greece	.025 – 0.5% of gross turnover	Revenue sharing	All licenses
India	6% - 10% of gross revenues	Revenue sharing	Fixed and mobile
Ireland	0.2% of gross turnover	Revenue sharing	Fixed and Mobile
Italy	EUR 38 million	Annual licensing fee	3G Mobile
Jordan	10% of gross revenues	Revenue sharing	Mobile
Kenya	0.5% of gross turnover	Revenue sharing	All licenses except paging
Luxembourg	0.2% of gross turnover	Revenue sharing	Mobile
Korea (Rep.)	Approximately 1- 3.0% of gross revenues (annual adj.)	Revenue sharing	All licensed operators
Spain	0.2% of gross turnover	Revenue sharing	Fixed Mobile
Venezuela	5.3% of gross revenues	Revenue sharing	Mobile

(Source: Dave Karan, Kumar Saurabh, Sarbjeet Kaur, Shubham Satyarth, and Valia Chintan. “Analyzing Revenue Sharing Model [sic] And Developing an Efficient Auction Framework.” (IPR, 2008).

3. Micropayments and real-time auctions: “pay-for-play” for the use of specific bands at a specific time.

Micropayments allow devices to utilize spectrum in return for small payments in real time or create a ‘spot’ market for spectrum access. Micropayments for spectrum access could help to facilitate an end-to-end network (i.e., one where the “intelligence” is at the edges of the network), but need both smart devices at the edges of the network as well open lines of communication and information to allow for device to quickly make decisions as to what frequencies are available and for how long. Micropayments could allow for the development of a system of open access similar to unlicensed spectrum within a licensed spectrum framework. For example a licensee could allow any number of devices to utilize its spectrum in real-time.[48]

Although, micropayments offer a promising model to increase secondary markets for spectrum use, there are a number of considerable challenges to overcome including the development of an infrastructure that would allow mobile devices to communicate with a licensee or regulator, request the right to use the spectrum, and agree on a real-time price, including mechanisms for authentication, transferring payments and monitoring usage.[49] Transaction costs remain considerable obstacle for the implementation of the model and must be less than the value of the spectrum to lessors.[50] As important, transactions need to be completed in a manner of milliseconds to limit latency on a network. A number of solutions have been proposed to increase the viability of micropayment and real-time auctions.[51] For example, Google as offered that web-based technologies could support a real-time auction at a fairly low-cost basis, just as it conducts real-time auction matching advertisers to search terms.[52]

Ensuring Fairness and Transparency

There are three key elements for ensuring fairness for micropayment regimes. First, pricing data must be made available in a transparent and accessible manner. However, when information is not made transparent, transaction costs rise and the model become far less viable. Second, the standards for smart devices must be technologically neutral and unencumbered by patents and other proprietary entanglements to encourage interoperability and economies of scale. Third, transaction costs must be kept to a minimum (and as close to zero as is possible) to ensure that seamless mobility across multiple networks is maintained.

Strengths

1. Potentially ties spectrum use more directly to demand.
2. Facilitates the re-purposing of underutilized or unused spectrum and secondary markets.
3. Lowers barriers to entry for new service providers.

Weaknesses

1. Without transparent pricing information and low transaction costs, the model will not function efficiently.
2. Works best when several networks or competitors are vying for customers.
3. Still requires additional research and development before capable of widespread deployment.

Optimal Spectrum Uses

1. Next generation cellular telephone and PDA networking (as indicated by Google's recent patent to create cellphones that could swap network providers based on “microauctions”[53]).

2. Emergency response and other situations where on-demand, supplemental capacity may be needed for existing telecommunications networks.
3. Wireless broadband networking.

Real-World Exemplars

1. Google patent on telephone system microauctions.
2. Several test-bed and simulated environments in laboratories around the globe.

4. Lite licensing: requirement to license a transmitter, but providing no primary or exclusive use of the frequency.

In 2005, the Federal Communications Commission opened up underutilized spectrum in the 3650 – 3700 MHz band to non-exclusive licensed use for fixed wireless broadband.[54] The rules created a streamlined license process to encourage multiple entrants and stimulate rapid utilization of spectrum by small Wireless Internet Service Providers (WISPs), especially in rural areas, while also protecting incumbent satellite and radiolocation users. This non-exclusive licensing scheme or "lite licensing" requires operators to register fixed and base stations at specific locations and to list their technical parameters in a common database. This database is then used by WISPs to coordinate their operations and minimize the potential for harmful interference with one another.

The approach has been extremely successful. Within the first year after the final FCC order in 2007, WISPs and other providers began deploying services in this spectrum band. Its use continues to increase, with an increasing number equipment manufacturers developing WiMAX equipment for this band. Contrast this with the spectrum auctioned AWS-1 band, which did not see any significant deployment even 18 months after the auction was completed and today, over two years later, remains substantially underutilized.[55]

Ensuring Fairness and Transparency

Licensing or registration process should be streamlined to limit the regulatory burden and costs for small operators. The common registration database should be easily accessible, with adequate information to limit the potential for interference. In addition, power limits and other mechanisms such as transmit power control[56] should be required to allow for a large number of concurrent users and to promote efficient use of the spectrum.

Strengths

1. Encourages rapid and intensive use of spectrum by limiting barriers to spectrum access.
2. Provides incumbent and/or grandfathered users with a high-level of interference protection from new spectrum users.
3. Facilitates cooperation among operators to coordinate spectrum usage to avoid harmful interference with one another.

Weaknesses

1. Tends to favor high-powered fixed point-to-point wireless services over low-powered services such as mesh networks.

2. Although non-exclusive, the approach can favor the first operator to register its services in a local area.[57]
3. Relies on mutual cooperation of operators to coordinate spectrum use. If spectrum becomes scarce in a particular area, voluntary cooperation may be inadequate and require the oversight agency to intervene to resolve spectrum use disputes.

Optimal Spectrum Uses

1. Fixed wireless broadband in rural areas where large blocks of open spectrum are available.
2. Fixed point-point wireless services such as those providing wireless backhaul for broadband networks.

Real-World Exemplars

1. The non-exclusive licensing or "lite licensing" approach is being utilized by the FCC in the 3650 – 3700 MHz band in the U.S.
2. Part 74 wireless devices (e.g., wireless microphones) use a similar technique whereby all eligible organizations may register a microphone, but none receive exclusive rights to the band.
3. The FCC's part 90 rules for private land mobile users in several bands employ a similar approach.[58]

5. Primary and secondary shared use: allow high power and low power uses to co-exist on the same frequencies.

The propagation characteristics of radio signals allows for the potential of very low-power unlicensed devices to operate on the same frequencies as high-power licensed devices through a concept called "interference temperature." As a wireless signal travels greater distances, the strength of the signal degrades. Depending upon the power level of a wireless transmitter, the signal will eventually become so faint that it will drop below what is known as the noise floor, where a receiver is unable to distinguish between the signal and background noise. As a consequence, to ensure a transmission reaches a receiver, the signal strength must always be greater than the noise floor.[59]

The noise floor consists of intentional or unintentional radiators and varies over time, location, and physical geography. In 2002, the FCC's Spectrum Policy Task Force (SPTF) proposed quantifying the noise floor levels on a band-by-band basis and permit unlicensed low-power wireless devices to operate below this level. SPTF recommended placing an interference temperature cap over the service area of a licensee that would offer licensed spectrum users "certainty with regard to the maximum permissible level of aggregated noise, or interference, in their band," and "to the extent that the interference temperature in a particular band is not reached, other users (*e.g.*, unlicensed devices) could operate in the same band – with the interference temperature serving as the maximum cap on the potential RF energy they could introduce in the band."[60]

In 2007, the FCC decided to terminate its inquiry into interference temperature, but did not completely abandon the concept. The FCC approved the use of a very low-power service known as Ultra-wideband (UWB) in the range from 3.1 GHz up to 10.6 GHz.[61] UWB devices operate under the same premise as the concept of "interference temperature," at power levels low enough not to interfere with existing users in the band. UWB is a wireless technology that allows tremendous throughput at close distances (e.g., 480 MB/sec over a 10-foot range or 120 MB/sec over a 100-foot range depending upon the standard) and is designed to replace wires such as USB, audio, and video cables. Through UWB, a digital camcorder could play a just-recorded video on an HDTV without wires, or a portable MP3 player could stream audio to high-quality surround-sound speakers anywhere in the room.[62] Although extensive research and development has occurred on bringing UWB devices to market, disagreements regarding industry standards have thus far limited consumer-ready devices.

Ensuring Fairness and Transparency
Given the opposition of the proposal to licensed users, any decision or inquiry would need to be as open and transparent as possible. Testing and analysis to determine interference temperature caps would need to open to public and allow for extensive public comment in order to set appropriate standards for low-power unlicensed devices operating on the same frequency as licensed user.

Strengths
1. Opens up considerable amounts of spectrum for unlicensed use.
2. Allows low-power unlicensed devices to scale-up in terms of throughput (speed) and capacity.
3. Permits more efficient use of spectrum through shared bands.

Weaknesses
1. Given the necessary power limits, devices would only be able communicate over very short distances.
2. Disagreements over industry standards may arise among competing technological organizations if interoperability is not mandated.
3. The proposal is controversial among most licensees and would require substantial regulatory overhaul.

Optimal Spectrum Uses
1. Devices designed to move data over very short distances.
2. Co-channel use is also best accomplished when very high-powered transmissions covering large areas are partnered with exceedingly low-powered secondary users.

Real-World Exemplars
1. Ultra-wideband

6. Unlicensed: opening a specific band to all devices that meet a specific set of technical specifications and requiring no licensing of these transmitters.

Unlicensed spectrum is widely used in a number of different products, in countries around the globe. For example, everything from microwave ovens to garage door openers, baby monitors to Wi-Fi equipped laptops all employ unlicensed spectrum. Originally, unlicensed spectrum such as the 2.4 GHz band was considered a "junk band" – with limited value and few possibilities for viable use. However, as digital radio technologies developed and the importance of inter-device connectivity grew, unlicensed spectrum provided the essential open platform to permit applications that could not be anticipated. With the advent of 802.11 standards, which first passed in 1997, the junk bands began to have a substantial and real social and economic value. As the technologies matured (in particular, with the passage of 802.11a and 802.11b in 1999 and 802.11g in 2003), the use of Wi-Fi increased dramatically.

Today, almost all new laptops are sold with Wi-Fi radios, as well as smartphones such as the iPhone and gPhone. Many airports, cafes, libraries and other public spaces provide wireless connectivity (either for free or for a fee). Unlicensed bands have also become a critically important driver for new technologies and broadband connectivity -- most small, independent wireless Internet service providers (WISPs), who do not have access to the capital to purchase spectrum at auction, make widespread use of the unlicensed bands to serve suburban and rural communities. In addition to WISPs, mainstream cellular providers like AT&T regularly use Wi-Fi to augment their own mobile broadband service offerings.

The benefits of unlicensed spectrum include more efficient use (i.e. more traffic can be carried) through spectrum sharing, reduced barriers to entry for new providers and greater experimentation and innovation.[63] The uptake of unlicensed band use has been so great that in many areas, additional unlicensed spectrum is needed to further expand service offerings and relieve congestion. Thus, one challenge to policy-makers is to ensure that ample unlicensed spectrum is made available to meet growing consumer demand. While the number of unlicensed wireless devices has increased by tens of thousands of percent over the past decade, the amount of spectrum allocated for their use has remained static. Current trends project that the number of unlicensed wireless devices will continue to increase at double-digit rates. Without this additional space, urban centers may find that the overcrowding of unlicensed bands will reach unprecedented levels in the coming years, thus dramatically lowering the utility of unlicensed bands.

The National Broadband Plan proposes the allocation of a new nationwide contiguous unlicensed band, although it did not specify where or how much spectrum.[64] Critics of allocating more spectrum for unlicensed often cite its inability to generate direct government revenues for spectrum use or the lack of property rights associated with a commons model. The former can be accounted for through the use of certification or device fees that could create a perpetual revenue source for the use of the spectrum. To preserve the property rights frameworks, one possible solution would be analogous to establishing a “land trust” or “national park” for unlicensed spectrum. In this model, the Federal government would purchase a block of spectrum and then open it for unlicensed use.[65] Moreover, state or local government could follow suit to establish their own public spaces within their more narrow geographic areas.[66]

Ensuring Fairness and Transparency

Ensuring fairness necessitates setting technological standards that support shared use as well as taking proactive steps to limit congestion in the bands. Unlicensed frequencies create an open commons for spectrum use, and similar to other commons, they can be exploited by nefarious users (especially since unlicensed devices receive no legal protections to operate and must accept whatever interference they receive). These challenges can be addressed in part through general rules of spectrum etiquette and interoperability.[67] For example, a device that has been transmitting for long periods at high power may receive de-prioritized access to the spectrum when contending with other devices.[68] Properly designed equipment will help alleviate potential tragedies of the commons; however, even with the best equipment available today, given the limited amount of unlicensed spectrum that is made available, congestion will be largely inevitable.

Strengths

1. Most unlicensed equipment is substantially cheaper than licensed equipment due to the large economies of scale created by standardized technology.
2. Many unlicensed technological standards have been set by the Institute of Electronics and Electrical Engineers (IEEE) and are royalty-free.
3. Widespread pre-existing adoption helps ensure that a myriad of options exist for consumers and network implementers.

Weaknesses

1. As uptake has increased, congestion has become a growing problem in some urban areas as well as for WISPs operating in suburban or exurban areas.
2. Many unlicensed bands are in frequencies with limited propagation characteristics (often needing line of site between receivers and transmitters).
3. Many unlicensed technologies are now "old" -- dating back to pre-cognitive radio technological development.

Optimal Spectrum Uses

1. Wireless hot spots and metro-scale wireless networks.
2. Off-the-shelf wireless devices (e.g., cordless phones, garage door openers, baby monitors, microwaves).
3. High-throughput point-to-point links with line of sight between the transceivers.

Real-World Exemplars

1. Wi-Fi (2.4 GHz and 5 GHz bands) – a.k.a. 802.11a/b/g/n.
2. 900MHz Industrial, Scientific, and Medical (ISM) Band (902-928 MHz) -- often used for cordless phones.
3. 57-64GHz and 92-95 GHz -- often used for high-bandwidth point-to-point links between wireless towers.

7. Opportunistic (re)use: Allowing devices to opportunistically identify unused frequencies and transmit on those bands.[69]

The Spectrum Policy Task Force's (SPTF) "Unlicensed Devices and Experimental Licenses Working Group" proposed another method of introducing innovation to exclusive-use bands by introducing "underlay" rights, thereby allowing unlicensed users to access the exclusive use bands in such a way that prevents interference with the license holder.[70] Advances in smart or cognitive radio (CR) and software defined radio (SDR) technologies have fundamentally expanded options for spectrum use. Traditionally, the spectrum scarcity rationale has led to difficulties in finding frequencies to support wireless broadband Internet. However, these technological advances have created opportunities for dynamic spectrum sharing, thus potentially ending the persistent problem of artificial scarcity of spectrum.[71]

This especially holds true for use within vacant spectrum, referred to as "white spaces," where cognitive radios, for example, rapidly scan and process spectrum use in real time, identify underutilized frequencies and can adapt to changes in this electromagnetic space.[72] Thus, within a given band, two transceivers can send data between each other while "frequency hopping" among available open frequencies. By opportunistically occupying unused frequencies within specific bands, these devices are far more efficient than traditional "dumb" technologies, which often broadcast on a single frequency regardless of other users.

In November 2008, the FCC opened up vacant television channels to unlicensed "white space" devices.[73] These devices are required to employ spectrum sensing technologies (so-called, "smart radios") and a geolocational database to automatically detect occupied television frequencies and other protected users in the band.[74] These technologies allow WSDs to identify and utilize the unassigned frequencies between broadcast television channels and outside the coverage areas of licensed broadcasters for digital communications—including broadband networks. While civilian use of WSD technology is awaiting technical specifications from the FCC,[75] the military has been testing similar WSD technology for years and has run numerous tests demonstrating its feasibility as a part of the DARPA XG project.[76]

Beyond the TV white space, the gelocational database under development could be expanded to include other underutilized licensed frequencies, including federal spectrum. Federal spectrum sharing through opportunistic access offers a more feasible approach to accessing valuable federal spectrum bands than clearing and auctioning. Through this approach, federal spectrum users could maintain access to frequencies when they need them, such as in times of emergency, while ensuring access when the spectrum would otherwise be idle. Such sharing could be accomplished through an active system like the aforementioned database, or passively through sensing such as the 5470 – 5725 MHz band where devices must vacate frequencies if they detect military radar signals.[77] The database also offers sufficient flexibility to possible incorporate a micro-payment or real-time auction mechanism to allow either the government or a current licensee to be compensated for offering access, although as discussed earlier issues of latency and transactions cost would need to be addressed.[78]

Ensuring Fairness and Transparency

Maintaining fair use of opportunistic spectrum access technologies requires ensuring access to information for all devices, the interoperability among devices (i.e., avoiding proprietary systems that do not cooperate with other devices), and avoiding dependencies within opportunistic access technologies. Opportunistic devices are also most efficacious when they can network and share information. Thus, for example, several devices that cooperate to sense their local RF environment (and share information about other users, occupied frequencies, etc.) operate far more efficiently than non-interoperable technologies. While several industry groups have already formed to address different elements of these technologies (e.g., the White Space Database Group and CogNeA Alliance), further attention will need to be paid to ensure that these efforts do not lead to closed standards. Finally, since opportunistic spectrum access technologies are so new, there is a danger of market capture by dominant players. Several companies have already announced their intentions to create white space devices (e.g., Philips, Motorola, Adaptrum), and it is unclear whether these systems will be built to interoperate with one-another and with third party technologies. Regulators can help lessen market uncertainties and ensure better outcomes by mandating interoperability and the publication and utilization of open standards for devices.

Strengths

1. Vastly increase the spectrum capacity available for unlicensed and dynamic use.
2. Do not displace existing spectrum users.
3. Can be implemented immediately with technologies available today.
4. Encourages efficient spectrum use through permitting dynamic access of unused or intermittently used spectrum.

Weaknesses

1. Face substantial political resistance from current license holders due to interference claims and its potential to devalue existing spectrum licenses by reducing the artificial scarcity of spectrum access.
2. May have trouble identifying pre-existing "dumb" transmitters (e.g., wireless microphones) in certain circumstances (current testing has, thus far, been inconclusive).
3. Is a relatively new technology that is still undergoing rapid evolution; thus, early adopters will need to be careful to avoid path dependencies or inadvertent obsolescence.

Optimal Spectrum Uses

1. Portable/mobile broadband devices.
2. Ad hoc networks (e.g., local networks within a house, business or emergency responders in remote locations) and other communications systems that may need local communications but not necessarily need to connect to the Internet itself.
3. Metro-scale wireless networks, wireless Internet service providers and other uses that require penetration into buildings, through trees, etc.

Real-World Exemplars

1. FCC order permitting unlicensed “white space” devices to operate on unused frequencies in the current television bands.
2. The DARPA-XG (Next Generation) project developed prototype dynamic spectrum access technologies that have been commercialized by a company called Shared Spectrum. These devices are currently being used in battlefield warfare to interconnect ground troops and ensure that remote devices like Predator drone ships cannot be jammed.
3. OFCOM in the UK approved the use of cognitive devices in "interleaved spectrum" in their TV band.[79]

Concluding Remarks

Today, communications technologies are rapidly changing and yet most spectrum policies and regulations still reflect 20th century technologies and thinking. As demand for spectrum continues to outpace current allocation methods, the FCC must account for these changes and broaden its spectrum thinking. This will require both the FCC and the nation's policymakers to explore much-needed spectrum allocation and licensure reforms to create a more dynamic spectrum ecosystem that is better tailored to meet the wireless needs of not just current large wireless incumbents and technologies, but new competitors, business models, civil society and the general public. The clear lesson to learn from the current environment is that a singular focus on auctions will not suffice in maximizing the public benefit or meeting public policy goals.

Advances in communication and other digital technologies have enabled entirely new approaches for spectrum licensure and use. End-user devices are "smart," capable of adapting to changing environments and maximizing efficient use of available spectrum to deliver mobile, affordable broadband connectivity. With continued advances in these technologies and in more efficient and shared use of spectrum, increasingly the historic scarcity rationale no longer holds, and traditional spectrum management strategies are becoming obsolete. As Nuechterlein and Weiser suggest, "Just as the First Amendment bars the government from limiting who can own a printing press," "it might well bar the government from restricting access to the airwaves as a medium of communication in the hypothesized world of super-abundant spectrum."[80] These arguments for expanded public access to the public's airwaves will only continue to proliferate as arguments for maintaining an outdated status quo—to the benefit of incumbent users and the detriment of innovation and the public—become decreasingly tenable.[81]

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1 Chairman Julius Genachowski, "Mobile Broadband: A 21st Century Plan for U.S. Competitiveness, Innovation and Job Creation," (speech, New America Foundation, Washington, D.C., February 24, 2010), http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-296490A1.pdf.

2 *Ibid.*

3 "The ongoing upgrade of the wireless infrastructure is promising because of its potential to be a closer competitor to wireline broadband, especially at lower speeds." Federal Communications Commission, "Connecting America: The National Broadband Plan," 2010, 41, http://download.broadband.gov/plan/national-broadband-plan.pdf.

4 *Ibid.* 81 – 82; *see also* Sanjay Talwani, "NAB 2010: Genachowski Emphasizes Spectrum Return Will Be Voluntary," *Television Broadcast*, April 14, 2010, http://www.televisionbroadcast.com/article/99044.

5 *See* Broadband.gov, "Broadband Action Agenda," Federal Communications Commission, http://www.broadband.gov/plan/broadband-action-agenda.html.

6 The FCC's auction website for a full list of US spectrum auctions (http://wireless.fcc.gov/auctions); however, the phenomenon has been global as other countries have followed the lead of the United States (which pioneered simultaneous ascending auctions in 1994) and New Zealand and Australia (which were among the first countries to utilize spectrum auctions in the 1980s and early 1990s). By 2000, spectrum auctions had been conducted in Australia, Austria, Belgium, Canada, Denmark, Germany, Guatemala, Israel, Italy, Mexico, the Netherlands, New Zealand, Switzerland, the United Kingdom, and the United States. For further discussion of the widespread adoption of spectrum auctions *see* Ian Munro, "Auctions as a Spectrum Management Tool," Presentation to the ITU Radiocommunication Bureau Seminar, November 8, 2000, www.itu.int/ITU-R/conferences/seminars/geneva-2000/docs/00-20_ww9.doc.

7 *See e.g.* Ellen P. Goodman, "Spectrum Auctions and the Public Interest," *Journal on Telecommunications and High Technology,* vol. 7 (2009): 343, http://jthtl.org/content/articles/V7I2/JTHTLv7i2_Goodman.PDF. The FCC's 700 MHz auction generated approximately $20 billion in revenues.

8 Based on an elaborate modeling of emerging cellular technologies (such as LTE and WiMAX) and cell densities, a 2006 ITU study concluded that advanced market economies would require total spectrum allocations of roughly 1,300 MHz by 2015 and 1,720 by 2020. Currently, wireless providers have access to just over 500 MHz. The ITU study estimated a considerably higher requirement for markets (such as the U.S.) that would desire sufficient capacity for three or four competing service providers in each market. The ITU's total spectrum requirement for three competing networks is 1,980 MHz and 2,240 MHz to support four competitive networks by 2015. *See* Michael Calabrese and Benjamin Lennett, *Mobile Data Demand and the Need for Increased*

Spectrum Access, (Washington D.C.: New America Foundation, Issue Brief #27, October 2009), 2, http://www.newamerica.net/files/CalabreseLennett_MobileDataDemand.pdf.

9 Jonathan E. Nuechterlein and Philip J. Weiser, *Digital Crossroads: America Telecommunication Policy in the Internet Age*, (London: The MIT Press, 2005), 226.

10 *See e.g.* Pierre de Vries, *Populating the Vacant Channels: The Case for Allocating Unused Spectrum in the Digital TV Bands to Unlicensed Use for Broadband and Wireless Innovation*, (Washington D.C.: New America Foundation, Working Paper No. 14, August 2006), http://www.newamerica.net/files/WorkingPaper14.DTVWhiteSpace.deVries.pdf.

11 Parts of the section were adapted from a previous article by the author. *See* Victor W. Pickard and Sascha D. Meinrath, "Revitalizing the Public Airwaves: Opportunistic Unlicensed Reuse of Government Spectrum," *International Journal of Communications* 3 (2009): 1068, http://ijoc.org/ojs/index.php/ijoc/article/viewFile/467/382.

12 *See e.g.* Tom Streeter, *Selling the Air*, (Chicago: The University of Chicago Press, 1996).

13 Ronald Coase, "The Federal Communications Commission" *Journal of Law and Economics* 2 (October 1959): 2.

14 *See e.g.* Thomas Hazlett, The rationality of U.S. regulation of broadcast spectrum, 33, *The Journal of Law & Economics*, 133 (1990). Though Hazlett suggests that Congress did not approve of property rights in spectrum, the de facto establishment of a property rights regime is largely what transpired.

15 This is, of course, a highly debatable assertion. It is noteworthy that two of the major figures he set out to challenge in his article were Charles Siepmann and Dallas Smythe. Both of whom were centrally involved in the FCC's 1946 "Blue Book" initiative that aimed to codify broadcasters' public service responsibilities.

16 Leading spectrum researchers such as Hazlett, Weiser, Hatfield have supported in their writings the basic principle that in many, if not most cases, spectrum is best utilized within a private property rights regime. Hazlett differs with Weiser and Hatfield regarding potential drawbacks. *See* Philip J. Weiser and Dale Hatfield, "Spectrum Policy Reform and the Next Frontier of Property Rights," *George Mason Law Review* 15, no. 3 (2008); Thomas W. Hazlett, "A Law & Economics Approach to Spectrum Property Rights: A Response to Professors Weiser & Hatfield, *George Mason Law Review* 15, no. 4 (Summer 2008).

17 David Moss and Michael Fein, "Radio Regulation Revisited: Coase, the FCC, and the Public Interest," *Journal of Policy History* 15 (2003).

18 For example, in the FCC's AWS-1 auction, the four biggest winners, T-Mobile, Spectrum Co., Verizon, and Cingular accounted for 71% of the total units of MHz-pop sold and 78% of total revenue. Similarly, in the 700 MHz auction, Verizon, AT&T and Frontier accounted for 80% of the total units of MHz-pop sold. *See* Patrick Bajari and Jungwon Yeo, "Auction Design and Tacit Collusion in FCC Spectrum Auctions," (University of Minnesota: March 31, 2009), 9 – 11, http://www.mysmu.edu/faculty/jwyeo/research/Bajari_Yeo_FCC.pdf.

19 *See* Mahesh Uppal and Payal Malik, "An Evaluation of Different Models for the Issuance of Licenses for Service Provision and Frequencies," (paper prepared for LIRNEasia Project on Mobile 2.0 at the Bottom of the Pyramid in Asia, August 2009), 3, http://www.lirneasia.net/wp-content/uploads/2009/08/Mobile2.0_Final_Hor_PM_03082009.pdf.

20 Jehiel and Moldovanu note "ex-ante estimates of expected consumers' surplus in future market scenarios are difficult to make. Therefore, consumers' surplus does not play a natural role in shaping the auction's outcome..." *See* Phillipe Jehiel and Benny Moldovanu, "License Auctions and Market Structure," (University of Mannheim, Department of Economics, September 2000), 2, http://www.sfb504.uni-mannheim.de/publications/dp01-21.pdf.

21 The authors wish to thank Victor Pickard for his background research on the topic. For further discussion on this issue and upon which portions of this paper are based *see* Pickard and Meinrath, "Revitalizing the Public Airwaves," *supra note* 11.

22 *See* Goodman, "Spectrum Auctions and the Public Interest," 352, *supra note* 8.

23 Peter Cramton, "Spectrum Auction Design," (University of Maryland, Department of Economics, August 11, 2009), 2, http://www.cramton.umd.edu/papers2005 2009/cramton-spectrum-auction-design.pdf.

24 *Ibid.*

25 Incumbents include in their valuation of spectrum at auction the benefit of preventing new entrants, which translate into increased willingness to pay for new licenses. *Ibid.; see also* Jehiel and Modavinue, "License Auctions and Market Structure," 2, *supra note* 20.

26 *See* Goodman, "Spectrum Auctions and the Public Interest," 354, *supra note* 8.

27 *See* Cramton, "Spectrum Auction Design," 3, *supra note* 23.

[28] *See e.g.* Nate Anderson, "Google attacks Verizon's attempt to water down 700MHz "open access" rules," *Ars Technica*, October 4, 2007, http://arstechnica.com/tech-policy/news/2007/10/google-attacks-verizons-attempt-to-water-down-700mhz-open-access-rules.ars.

[29] *See* Cramton, "Spectrum Auction Design," 2, *supra note* 23.

[30] *See* Bajari and Yeo, "Auction Design and Tacit Collusion in FCC Spectrum Auctions," 11, *supra note* 18.

[31] *See* Cramton, "Spectrum Auction Design," 3, *supra note* 23.

[32] Vodafone and BT Cellnet before the auction agreed to offer roaming voluntarily. *See* Ken Binmore and Paul Klemperer, The Biggest Auction Ever: the Sale of the British 3G Telecom Licences [sic]," (September 2001), http://www.nuff.ox.ac.uk/users/klemperer/biggestsept.pdf.

[33] Karen Wrege's analysis provides a concise synopsis of the necessary criteria for ensuring a fair and transparent auction process. *See* KB Enterprises LLC, "Spectrum Auctions in Developing Countries: Options for Intervention," (prepared for the Open Society Institute, March 31, 2009), http://kbspectrum.com/wp-content/uploads/2009/10/Soros-OSI-033109-Spectrum-Auctions-in-Developing-Countries-Options-for-Intervention.pdf.

[34] Simon Wilkie, "Spectrum Auctions Are Not A Panacea: Theory And Evidence Of Anti-Competitive And Rent-Seeking Behavior In FCC Rulemakings And Auction Design," (prepared for M2Z Networks, Inc., March 26, 2007), v, http://www.m2znetworks.com/xres/uploads/documents/Wilkie%202%20Auctions%20No%20Panacea%20Wilkie.pdf.

[35] Rent-seeking behavior includes, delaying the decision-making process through long-drawn debates over service rules, un-specifiable and unquantifiable arguments of technical interference or slicing new available bands for private commercial use in ways that make it more costly or impossible to build upon such license a viable national competitive business plan. *Ibid.*; *see also* Cramton, "Spectrum Auction Design," *supra note* 23. Cramton recommends the use of a "package clock" auction to determine for example e band plan specifying how the spectrum is organized.

[36] Spectrum warehousing) occurs when an incumbent license holder bids for spectrum to keep it out of the hands of opponents but does not necessarily wish to make use of that band themselves. In essence, license winners warehouse the spectrum and may or may not actually make use it at a future date. Many telecom incumbents own bands that they are not currently using, particularly in sparsely populated areas. Spectrum flipping occurs when one bids on a spectrum band with the expectation that you can either resell or rent the spectrum to a third party. Thus, the goal of winning the auction is not directly to make use of the spectrum but rather to sell or rent the resource.

[37] *See e.g.* Jeheil and Moldovanu, , "License Auctions and Market Structure," 2, *supra note* 20. "The difficulty in achieving efficiency is due to the fact that consumers do not directly participate at spectrum auctions."

[38] Jon M. Peha, "Spectrum Management Policy Options," *IEEE Communication Surveys* 1, no. 1 (Fourth Quarter 2008), 6, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.35.927&rep=rep1&type=pdf

[39] As Peha acknowledges, "auction winners must still be required to make a non-refundable payment immediately. This discourages firms from bidding artificially high and using the threat of non-payment (or bankruptcy) to negotiate for lower payments, as occurred in the U.S. PCS auctions. This practice thoroughly undermines the advantages of auctions." *Ibid.*, 6.

[40] *See* Adele C. Morris, *The Taxation of Spectrum Rights: Tools for Efficiency and Distribution*, (August 31, 2006), 6, http://web.si.umich.edu/tprc/papers/2006/570/Property%20taxation%20of%20spectrum%20v2.pdf.

[41] *Ibid.*, 9.

[42] *See* Dave Karan, Kumar Saurabh, Sarbjeet Kaur, Shubham Satyarth, and Valia Chintan, "Analyzing Revenue Sharing Model [sic] And Developing an Efficient Auction Framework," (IPR, 2008), 9.

[43] *Ibid.*, 36.

[44] *Ibid.*, 6.

[45] *Ibid.*

[46] *See e.g.* Shauvik Ghosh and Rahul Chandran, "Telcos now get audit call from CAG," *livemint.com*, March 6, 2010, http://www.livemint.com/2010/03/16234616/Telcos-now-get-audit-call-from.html.

[47] Note that the BBC is funded primarily by an annual television license fee charged to all UK households, companies and organizations using equipment capable of recording and/or receiving live television broadcasts. *See e.g.* TV Licensing, "TV Licensing and the Law," TV Licensing - Legislation and policy, http://www.tvlicensing.co.uk/about/legislation-and-policy-AB9/#link1.

[48] *See* Peha, "Spectrum Management Policy Options," 3, *supra note* 37.

[49] *Ibid.*

[50] Gerald R. Faulhaber and David J. Farber, *Spectrum Management: Property Rights, Markets, and The Commons*, (AEI-Brookings Joint Center for Regulatory Studies, Working Paper 02-12, December 2002), 20, http://www.cs.cmu.edu/afs/cs.cmu.edu/user/dmaltz/100x100/WWW/papers/faulhaber-brookings2002.pdf.

[51] *Ibid.*, 20. "there exist institutions that can handle this problem at minimum transactions cost, even without the magic of computers. A similar situation rises in the payment of royalties owed to musicians every time a song is played on the radio or in a jukebox;" *see also* Sorabh Gandhi, Chiranjeeb Buragohain, Lili Cao, Haitao Zheng, Subhash Suri, *Towards Real-Time Dynamic Spectrum Auctions*, (University of California, Department of Computer Science), 2, http://www.cs.ucsb.edu/~htzheng/publications/pdfs/auction-journal08.pdf.

[52] *See* Michael Calabrese, *The End of Spectrum 'Scarcity': Building on the TV Bands Database to Access Unused Public Airwaves*, (Washington, D.C.: New America Foundation, Working Paper no. 25, June 2009), 11, http://www.newamerica.net/files/Calabrese_WorkingPaper25_EndSpectrumScarcity.pdf

[53] Google's patent would facilitate, "Devices, systems, and methods for providing telecommunication access and applications to users in a flexible manner. Devices may operate on multiple networks, and may in certain circumstances seek out bids from telecommunication service providers." For further discussion and a link to the original patent *see e.g.* David Chartier, "Google patent would swap cellular contracts for miniauctions ," *ars technica*, September 26, 2008, http://arstechnica.com/old/content/2008/09/google-patent-would-swap-cellular-contracts-for-miniauctions.ars.

[54] *See* Federal Communications Commission, *Report and Order and Memorandum Opinion and Order*, ET Docket No. 04-151, March 10, 2005, http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-05-56A1.pdf.

[55] *See e.g.* Harold Feld, "How to Give America Wireless Broadband for Christmas 2009 — the Lesson from 3.65 GHz Deployment," Tales From the Sausage Factory, entry posted January 29, 2008, http://tales-of-the-sausage-factory.wetmachine.com/content/how-to-give-america-wireless-broadband-for-christmas-2009-the-lesson-from-365-ghz-deployment.

[56] Transmit power control requires devices to limit their operating power to the minimum necessary for successful communication.

[57] Although the registration process does not provide an operator with exclusive rights or protection from other "licensed lite" users, it may give the first operator an advantage in terms of transmitter placement or force a new entrant to pursue an alternative deployment strategy to avoid interference.

[58] *See* 47 CFR 90.173.

[59] *See e.g.* Kevin Werbach, "Supercommons: Toward a Unified Theory of Wireless Communication," *Texas Law Review* 82: 863-973, http://werbach.com/research/supercommons.pdf.

[60] *See e.g.* Federal Communications Commission, *Spectrum Policy Task Force Report*, ET Docket 02-135, November 2002, http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228542A1.pdf.

[61] *See* Federal Communications Commission, *First Report and Order*, ET Docket No. 98-153, April 22, 2002, http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.pdf.

[62] For further discussion of ultra-wideband *see* Intel, "Ultra-Wideband (UWB) Technology," Technology & Research at Intel, http://www.intel.com/technology/comms/uwb.

[63] *See* Peha, "Spectrum Management Policy Options," 2, *supra note* 37.

[64] *See* Federal Communications Commission, *Connecting America: The National Broadband Plan*, 94 – 95, *supra note* 3.

[65] *See* Faulhaber and Farber, *Property Rights, Markets, and the Commons*, 26, *supra note* 50.

[66] *Ibid.*

[67] *See e.g*. Joe Bate, Hwee-Pink Tan, Kenneth N Brown, Linda Doyle, *Maximising* [sic] *Access to a Spectrum Commons using Interference Temperature Constraints*, (Centre for Telecommunications Value-chain Research, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.101.4621&rep=rep1&type=pdf; Jon Peha, *Sharing Spectrum through Spectrum Policy Reform and Cognitive Radio*, Jon M. Peha (Carnegie Mellon University, Draft Paper), http://www-net.cs.umass.edu/691cr-10/Peha_Proc_of_IEEE.pdf.

[68] As Peha notes, "it is likely that any approach that discourages greed will be incompatible with some applications, such as broadcast radio and television, which need to transmit continuously. Indeed, different rules of coexistence will be more conducive to different applications, so there is no single set or rules that is optimal." *See* Peha, "Spectrum Management Policy Options," 2, *supra note* 37.

[69] This section was adapted from Pickard and Meinrath's, "Revitalizing the Public Airwaves: Opportunistic Unlicensed Reuse of Government Spectrum," *supra note* 11.

[70] *See* Federal Communications Commission, *Spectrum Policy Task Force Report*, *supra note* 60.

71 For one of the earliest statements on the potential of cognitive radios and the paradigm shift from static to dynamic spectrum use, *see* Kevin Werbach, *Radio Revolution: The Coming a Age of Unlicensed Wireless*, (Washington, DC: New America Foundation, Public Knowledge, 2002).

72 Some analysts suggest that at any given time the majority of the current spectrum could be technically considered a "white space." *See* Mark McHenry, *Dupont Circle Spectrum Utilization During Peak Hours, A Collaborative Effort of The New America Foundation and The Shared Spectrum Company*, (Washington, DC: New America Foundation, 2003), http://www.newamerica.net/files/archive/Doc_File_183_1.pdf.

73 *See* Federal Communications Commission, *Second Report and Order and Memorandum Opinion and Order,* ET Docket No. 04-186, November 14, 2008, http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-08-260A1.pdf.

74 Steven K. Jones and Thomas W. Phillips, Federal Communication Commission, Office of Engineering and Technology, *Initial Evaluation of the Performance of Prototype TV-Band White Spaces Devices*, OET Report FCC/OET 07-TR-1006, July 31, 2007, http://fjallfoss.fcc.gov/edocs_public/attachmatch/DOC-275666A1.pdf.

75 The FCC tested several white space devices at the August 9, 2008 pre-season game between the Washington Redskins and the Buffalo Bills, held at FedEx Field in Landover, MD and in New York City during the week of August 11, 2008 to test the devices during a *Phantom of the Opera* Broadway show. *See e.g.* Chloe Albanesius, "White Spaces Tech to Be Tested in NFL in August," *Pcmag.com*, Aug. 5, 2008. http://www.pcmag.com/article2/0,2817,2327245,00.asp.

76 *See e.g.* Shared Spectrum Company, "Darpa XG Program Information," SSC – Technology, http://www.sharedspectrum.com/technology/darpaxg.html; Shared Spectrum Company, *Shared Spectrum Company Succesfully Demonstrated next Generation (XG) Wireless Communication System* (Shared Spectrum Company, Press Release, Sept. 18, 2006), http://www.sharedspectrum.com/inc/content/press/XG_Demo_News_Release_060918.pdf.

77 *See* Benjamin Lennett, *Good Enough for the Pentagon: The Feasibility of "Smart Radio" Technology in the TV White Spaces*, (Washington, DC: New America Foundation, October 2008), http://www.newamerica.net/files/nafmigration/Good_Enough_for_the_Pentagon.pdf.

78 *See* Michael Calabrese, *The End of Spectrum 'Scarcity': Building on the TV Bands Database to Access Unused Public Airwaves*, (Washington, DC: New America Foundation, Working Paper no. 25, June 2009), 11, http://www.newamerica.net/files/Calabrese_WorkingPaper25_EndSpectrumScarcity.pdf

79 *See* OFCOM, *Digital dividend: cognitive access*, July 1, 2009, http://www.ofcom.org.uk/consult/condocs/cognitive/statement/statement.pdf.

80 Nuechterlein and Weiser, *Digital Crossroads,* 230, *supra note* 10.

81 For example the share of the DTV band (channels 2-to-51) that will be vacant after the February 2009 end to analog transmission ranges from 30 percent in the most congested, coastal markets (e.g., Trenton, N.J.) to 80 percent or more in small town and rural markets. *See e.g. Measuring the TV "White Space Available for Unlicensed Wireless Broadband*, (Washington, DC: New America Foundation, Nov. 18, 2005), 3, 25–27, 49–51, http://www.newamerica.net/publications/policy/measuring_tv_white_space_available_for_unlicensed_wireless_broadband.