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Revitalizing the Public Airwaves:

Opportunistic Unlicensed Reuse of Government Spectrum

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I. INTRODUCTION

The time has arrived for the unmet potentials of federal white spaces to receive some well-deserved attention. While many policy analysts have focused on the fate of the 700 MHz auctions, the digital TV transition, and the promise of television white space devices, the best available data suggests that the majority of federal spectrum capacity is left unused (McHenry, 2003; McHenry, 2004) – a situation that has gone largely unexamined. Strategic reuse of this spectrum could help obviate the need for significant additional frequency reallocations while enabling a wide range of creative new uses and social benefits. Based on what little information is publicly available, it is reasonable to assume that the repurposing of government spectrum would go far in addressing a number of access-related communication problems. Repurposing currently unused U.S. government-controlled spectrum for opportunistic unlicensed use would benefit society by dramatically expanding access to high-speed broadband and increasing the pace of wireless technological innovation. This approach to spectrum policy presents a "third way" for reform, drawing from both the commons and property rights models of spectrum management.

WIRELESS FUTURE PROGRAM

The FCC and NTIA have continued to privilege an outdated model for licensure that allows only a single entity to broadcast on a given frequency, often at a specific power level and geographic location – resulting in an abundance of underutilized government spectrum that could be shared with a wide-range of important services. Advances in smart technology-enabled spectrum sharing will be able to simultaneously open this underutilized spectrum while protecting legacy federal users.

A growing consensus among engineers and analysts holds that recent and imminent technological improvements in the realm of cognitive radio technologies make it possible to strategically "borrow" unutilized spectrum in real time. By using a resource that would otherwise go to waste, intelligent wireless devices can provide a means for building new and complementing existing telecommunications infrastructures. If employed on a wide scale, policies that open up government spectrum for opportunistic unlicensed reuse have the potential to essentially eliminate the artificial scarcity that too often hinders efforts to develop next generation wireless communications systems. This shift in spectrum regulation could also help remedy America's falling international ranking in broadband penetration by dramatically lowering the costs of communications, fostering a new wave

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of geolocational and social networking services and applications, and driving implementation projects throughout the United States.

In this paper we address the following questions: What is the reported utility of the federal spectrum? What data on current usage rates are publicly available? How can we protect existing uses while allowing unlicensed access? What technologies are needed for opportunistic unlicensed spectrum reuse? Based on open-ended, off-the-record discussions with government officials and an analysis of policy documents, this paper sketches competing normative assumptions underlying possible regulatory policies and examines spectrum use vis-à-vis its unmet potentials for maximizing social benefits. After examining some of the key debates regarding spectrum management models, we propose a "third way" argument that opportunistic reuse of government spectrum on an open and unlicensed basis affords the greatest value to the general public. We explain how the government's tendency to auction off spectrum to raise revenue on a one-time basis is not ideal to ensure the advancement of new technologies and expanded broadband access for underserved areas. The paper concludes with a series of policy recommendations for implementing opportunistic reuse of government spectrum. By exploring models for spectrum management that take advantage of technological innovations, our analysis aims to help initiate a policy debate on spectrum reforms that may hold profound implications for the future of U.S. communications.

II. SPECTRUM MANAGEMENT REGIMES

There are few communication policy issues that strike at the heart of political economic concerns like questions of spectrum management. These questions include the following: Who receives access to the spectrum and for what purpose? Whose interests are being served? And what public interest obligations are attached to a licensee's use of the public airwaves? When discussing how spectrum is controlled, we are really discussing issues of power. These issues are complicated by what Nuechterlein & Weiser call the "twin peculiarities" for air transmissions using spectrum; more specifically, a lack of obvious property rights in frequency assignments and a constant threat of interference between one service or user and others (Nuechterlein & Weiser, 2005, 229). These peculiarities have engendered a long and colorful history of regulatory dilemmas and power struggles over spectrum management.

In theory and in law, the airwaves belong to the public. However, decisions regarding who gets to use the airwaves, for what purpose, and subject to what conditions, are contentious, inviting close governmental regulation predicated on a rationale of spectrum scarcity. Traditionally, the FCC has allotted spectrum for the exclusive use of designated private parties. Despite the fact that the airwaves belong to the entire American polity, the historical record suggests that spectrum in the United States has been monopolized by commercial interests with little concern for the public interest (McChesney, 1993; Pickard, 2008). However, this state of affairs was not inevitable and with the right policy interventions combined with new technological capacities, the potential for changing course remains. Any path to reforming the spectrum management regime leads through two regulatory bodies, the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA), and involves issues related to public and federal access to the airwaves.

A. Regulating Access to the Airwaves

The question of access is a critical element in determining whether a communications system is being operated in an open and free manner. Communication bottlenecks undermine the types of services offered, create artificial scarcity, and lead to increased pricing. Such vulnerabilities are exemplified by U.S. spectrum policy surrounding the licensure of the public airwaves, which dates back to the 1927 Radio Act, the 1934 Communications Act, and the founding of the Federal Communications Commission (FCC). The FCC, which holds jurisdiction over all non-Federal spectrum uses, including state and local public safety, makes frequency assignment decisions based primarily on the model of exclusive licenses. Although not all spectrum is divvied up in this manner, over 95 percent of the public airwaves (under 30 GHz) are either reserved for governmental use or licensed to private parties (Kobb, 2001; NTIA "Redbook," 2008).[1]

Although tiny slivers of so-called "unlicensed" frequencies have generated enormous economic activity and innovation (everything from Wi-Fi devices to baby monitors and cordless phones co-exist within these rare frequencies), they are an exception to a regulatory norm that systematically fails to take advantage of the potential efficiencies of advanced communications technologies (New America Foundation, 2003). Wi-Fi use at 2.4 GHz and 5.8 GHz is a major success story for unlicensed spectrum, but the model has not yet been replicated widely in other spectrum areas despite its proven benefits. In 2002, a "Spectrum Policy Task Force" was established to help the FCC identify needed reforms to better utilize radio spectrum. The task force released several promising reports that helped spur discussion on opening vacant channels in the television spectrum for unlicensed use, but it was disbanded in 2005 (FCC, 2002). Unlike spectrum access for private, state and local governments' use authorized by the FCC, any federal government use of spectrum falls under the jurisdiction of another regulatory body, the National Telecommunications and Information Administration. Given our focus on Federal spectrum, the remainder of the paper primarily deals with spectrum policy issues that fall under the NTIA's purview.

B. The NTIA and Federal Access to the Airwaves

The NTIA was formed as a sub-agency of the Commerce Department in 1978 to serve as the President's principal adviser on telecommunications and information policy, and to manage federal government's use of spectrum, including military use. Headed by the Assistant Secretary for Communications and Information, NTIA relies on the assistance of one of the oldest federal agencies, the Interdepartmental Radio Advisory Committee (IRAC), which NTIA now chairs. IRAC, which helps coordinate federal use of spectrum, is composed of representatives from twenty federal agencies that rely on spectrum in carrying out their various responsibilities.[2] In addition to the main IRAC members, over four dozen additional governmental organizations use spectrum and must coordinate their needs via the NTIA.[3] Like the FCC, the NTIA allocates spectrum on the basis of an exclusive use by a licensee.[4]

Reallocations of government spectrum are difficult for a number of reasons. They involve coordination between the FCC and the State Department to develop a joint position that is then presented before the United Nation's International Telecommunications Union (ITU). Ideally, this process could at least be partially circumvented via spectrum sharing (discussed below), which is not a reallocation, but rather a repurposing that does not necessitate a dramatic shift in spectrum assignments. Nevertheless, government spectrum holders have little incentive to abdicate unneeded spectrum since they do not pay even a nominal fee. A presidential task force was formed in 2003 to develop recommendations for federal agencies to utilize spectrum more efficiently. Two promising reports came out making recommendations for ascertaining underused federal spectrum.[5] The task force also helped create the Commerce Spectrum Management Advisory Committee (CSMAC).[6] A report came out in March 2008 with some recommendations (discussed below), but thus far the issue has gained little attention (Nuechterlein & Weiser, 234; NTIA, 2003). The lack of movement can be at least partially attributed to institutional factors. The NTIA is more shielded from public pressures to disclose information and is less transparent compared to the FCC. J.H. Snider notes that specific federal agencies—not the NTIA—make most decisions regarding federal government spectrum use. Another significant distinction is that, unlike the FCC, the NTIA is not subject to the Administrative Procedure Act, and is therefore far less accountable to the public. Information such as spectrum assignments does not have to be made public. Non-classified information held by the NTIA must be obtained via Freedom of Information Act (FOIA) requests (Snider, 2006). Snider spent over a year attempting to acquire information from the various government agencies via FOIA requests but was thwarted at every turn. The NTIA keeps all of the information regarding federal allocations in a somewhat secretive database known as the Government Master File. At the moment, even federal agencies themselves have a difficult time finding information on federal spectrum. The NTIA also lacks the FCC's resources, making reallocation costs more difficult.

C. Government Spectrum Allocations and Uses

Government spectrum allocations range from weather surveillance and fire watching by the U.S. Forest Service to ship monitoring and national security measures by the military. Available data suggests that a significant amount of this spectrum is under-utilized, and could at least be shared if not reallocated (McHenry, 2003; McHenry, 2004). There are several challenging aspects in dealing with government allocations that complicate reallocation efforts. First, it is difficult to locate where they are located. Understandably, spectrum set aside for military use is often kept classified, but even information showing how various agencies are using particular swaths of spectrum is unnecessarily opaque.[7] Moreover, the relatively scarce information available online is often outdated.[8] Second, the use of particular bands may change with the season or the region. For example, some bands might be designated for communications during fire season in the Western states, but otherwise remain unused. The lack of publicly available data on precise federal spectrum location and uses renders this paper more of a preliminary intervention rather than an in-depth analysis that would be possible if more information (and additional spectrum use measurements) were publicly available. Nevertheless, there is increasing evidence suggesting that if we were to find and apply spectrum-sharing technologies in utilizing federal spectrum, the problem of broadband scarcity would be substantially alleviated and wireless technological innovation greatly enhanced. While these arguments have been employed in cases involving white spaces and other under-utilized pieces of spectrum, little attention has been given to government-monopolized spectrum.

It is estimated that the federal government wholly controls over 13 percent of all allocated spectrum bands and shares around 56 percent of all other bands, which translates to 270,000 frequency assignments to federal agencies (Nuechterlein & Weiser, 233-4). Although it is rather imprecise about exactly which agencies control what spectrum, one NTIA chart estimates that 81.83 percent of the spectrum between 3MHz and 30MHz is allocated to the Federal Government.[9] Research by J.H. Snider calculates that federal government and shared spectrum account for 64 percent of all allocations under 3.1 GHz (2003). One of the biggest blocks is found at 225 – 400 MHz, which, according to Ben Kobb's *Spectrum Finder*, "is devoted to military aircraft, tactical and training communications, satellite links for ground, air, surface and subsurface users, rocket test and telemetry, position location networks and Presidential communications." There is reason to believe that not all of this spectrum is being well utilized because, as Kobb notes, "The FCC called on the government to offer some of this spectrum to the private sector," but the Department of Defense (DOD) "takes a dim view of such assertions. It regards to the 225 – 400 MHz band as the single most critical spectrum resource of the military tactical forces." (p. 91). There are large sections of government spectrum between 902 and 1850 MHz and smaller swathes at 108 – 174 and 400 – 450 MHz.

Although general allocation data is available, current usage rates are difficult to ascertain given both the datedness and scarcity of data made available by authorities such as the NTIA and IRAC. Based on a variety of sources, however, we can begin to make empirically-backed estimates as to how federal spectrum is being used. It is generally assumed that the DOD is the leading user of government spectrum.[10] Other groups' spectrum usages are listed in the NTIA's Federal Strategic Spectrum Plan. For example, the report lists the Department of Agriculture's Forest Service use of conventional land mobile radio systems as concentrated in three bands: 162174 MHz, 406.1 – 420 MHz, and 1710 – 1850 MHz (Spectrum Plan, B-160). Similar information is listed under each agency in terms of current use and future needs. However, it is difficult to know for sure how much of this spectrum is actually being used at any given time.

While hard data on actual spectrum use is remarkably difficult to find, frequency use data were collected in six locations along the East coast in 2004 and documented an average total spectrum use of less than 10 percent (3.4 percent in Great Falls, Virginia, 6.9 percent in Vienna, Virginia (location 1), 11.4 percent in Arlington, Virginia, 13.1 percent in New York City, New York, 1.0 percent in Green Back, West Virginia, and 11.7 percent in Vienna, Virginia (location 2). What is clear from these data is that even in the midst of New York City during a national convention (when a far higher-than-average use of law enforcement and federal agency spectrum would be expected), the vast majority of the public airwaves still remains unused (McHenry, 2004). Another compelling study based in Washington D.C. indicated that government spectrum was grossly underutilized in a major metropolitan center (McHenry, 2003).

Other data further raise questions about how federal agencies are using spectrum. Material retrieved through the Freedom of Information Act kept in the New America Foundations' archives—documents that J.H. Snider spent months tracking down in 2004 and 2005—contains a list of government agencies and the number of spectrum assignments from 2004. Some of the organizations that have spectrum are somewhat counter-intuitive. For example, the Supreme Court has been given 13 "assignments" of spectrum; the Library of Congress 9; the National Archives and Records Administration, 6; the National Gallery of Art, 12; the Smithsonian, 73. The precise measurement of "no. of spectrum" is still unclear, and pales in comparison to the Department of Energy's 9,312 and the Air Force's 28,227. Nonetheless, despite its ambiguity, this data raises vexing questions about how government spectrum is being utilized.

D. The Federal Spectrum Strategic Plan

In 2003, President Bush announced the "Spectrum Policy Initiative," thus establishing a "U.S. spectrum policy for the 21st Century that will foster economic growth; ensure our national and homeland security; maintain U.S. global leadership in communications technology and services; and satisfy other vital U.S. needs in areas such as public safety, scientific research, Federal transportation infrastructure, and law enforcement"(Whitehouse, 2003). In 2004, as part of this initiative, the President directed Federal agencies to formulate, within one year, agency specific strategic spectrum plans that include spectrum requirements for future technologies or services, planned uses, and suggested spectrum efficient approaches to meeting these requirements (Whitehouse, 2004).

Finally released in March, 2008, the Federal Spectrum Strategic Plan is a mere 13 pages, but is followed by 200-plus pages of appendices that describe in some detail the uses of spectrum by major federal agencies.[11] Instead of pointing out places where spectrum is underutilized, most of the agencies make the case for needing more spectrum. One exception is where the Department of Transportation explicitly identifies seven frequency bands that "are no longer needed to support its mission requirements: 9 – 14 kHz; 90 – 110 kHz; 4400 – 4500 MHz; 16.2 – 17.7 GHz; 24.250 – 24.650 MHz; 25.250 – 27.5 GHz; and 36 – 38.6 GHz." The Department of Agriculture's Forest Service's use of conventional land mobile radio systems, which is concentrated in three bands: 162 – 174 MHz, 406.1 – 420 MHz, and 1710 – 1850 MHz, recently vacated the 1710 – 1755 MHz band that was auctioned for advanced wireless services. The Department of Energy and Tennessee Valley Authority also vacated from this band, suggesting at least the possibility that these agencies might be sitting on more under-utilized spectrum (Spectrum Plan, pp. B-160, 179, 212). Given that at least three agencies had to vacate the same spectrum bands suggest that these are very general parameters.

The Spectrum Plan's policy prescriptions are generally vague, although it makes references to a "new spectrum management model" that aims for "dynamic spectrum access" based on time, location, and frequency. While making allowances for expanding military needs, the report also articulates the need for expanded spectrum access for "private sector growth and innovation," as well as to "more efficiently utilize the spectrum resource through economic and non-economic incentives." It further mentions "incentive mechanisms," including "secondary markets, property rights, sharing and fees" (Spectrum Plan, p. 10). The concluding recommendations section avows to continue incrementally improving upon spectrum management, but does not go into specifics. However, there are some noteworthy statements earlier in the report. For example, the Spectrum Plan states, "Many agencies plan to implement smart technologies such as SDR." It further notes that the "NTIA is monitoring the development of such spectrally efficient approaches and encourages additional technology developments, particularly in the area of dynamic spectrum access. The NTIA will look to both the government and private sector for assistance and support in devising the necessary plans and strategies that will allow evolution of the spectrum management system..." (Spectrum Plan, p. 9). The report lists a number of improvement measures such as "narrowbanding land mobile channels" and increasing "management flexibility with land mobile service national frequency allotment plans" (Spectrum Plan, B-6, B-7). According to the report, the largest Federal users of the land mobile service are the DHS, Army, Air Force, Navy, DOI, and DOJ (p. B-10).

In summary, the Spectrum Plan advocates new policies and incentives for sharing underutilized federal spectrum with non-federal entities. Of significant note, the NTIA report concludes—very similarly to our own assessment—that "Currently, regulatory hurdles prevent federal and non-federal spectrum users from efficiently sharing spectrum..." (Spectrum Plan, p. 9-10). Elsewhere the report notes, "Several agencies had called for rule changes and policy reforms to improve interoperability and sharing in emergencies." It also notes that the "NTIA, with the advice of [IRAC], recently took steps to address the need for non-Federal entities to use public safety spectrum in appropriate situations" (Spectrum Plan, p. 10). Based on lessons learned from Hurricane Katrina, the need to share spectrum during emergencies is abundantly clear.[12] The NTIA seems amenable to this and other sharing imperatives. However, while appearing to be advocating for sharing federal spectrum with non-federal users via smart technologies, the NTIA report is vague about implementation. Moreover, any implementation will require data on actual use, including both the allocated use and the claimed use by licensees. Although the existence of this data is presumed given the frequent references to "underutilized" spectrum (and a single mention of the Government Master File), more precise information is needed (p.3).

III. A NEED FOR SPECTRUM REFORM

The FCC and NTIA have continued to privilege a model for licensure that allows only a single entity to broadcast on a given frequency, often at a specific power level and geographic location. This "command and control" mentality of spectrum management—by which the FCC and NTIA allocate spectrum into bands, assign and prescribe how these bands will be used, and oversee the method of giving exclusive rights to specific licensees—is woefully outdated given current technologies and spectrum needs. While digital technologies have radically transformed almost every facet of current society, the U.S. licensure regime is predicated on use of the public airwaves as if we were still utilizing pre-computer (analog) technologies dating back to the World War I era. Tim Wu wrote an op-ed in the *New York Times* likening U.S. spectrum policies to "Soviet Style Rules…[governing]… a command and control system dating from the 1920s". Wu estimates that "At any given moment, more than 90 percent of the nation's airwaves are empty" (2008). Other analysts referred to current spectrum management policy as a "paradigm for economic inefficiency" (Weiser & Hatfield, 2005). Whether one looks at the debate over low-power FM radio licensure, interference temperature, or unlicensed devices in unused television broadcast bands, the story is invariably the same: incumbent interests already invested in licensed frequencies seek to prevent competition by maintaining the antiquated regulatory status quo. In this way, incumbents dramatically slow down change or stop it altogether. "Among neutral observers," Nuechterlein & Weiser note, "there is little dispute that…the current spectrum regime requires a comprehensive overhaul" (p. 239). With such an overhaul in mind, an in-depth reassessment of federal spectrum policies is a necessity.

A. Models of Spectrum Reform

Generally speaking, in recent years two conflicting models have repeatedly faced off in discussions on spectrum management policy reform: the property rights and the commons approach. The former is most often associated with Ronald Coase (1959) and the latter is given clearest expression by Yochai Benkler (2006). Fierce debates have raged between these two camps over the past several years. We do not wish to merely rehash what is by now a fairly familiar argument. However, a brief overview of this debate is necessary for us to provide the foundation upon which we attempt to argue for a third way for spectrum reform that assumes unlicensed use (a major component of the commons model) but protects primary license holders (a major component of the property rights model).

The commons model views spectrum as a public resource to be shared. In this sense, the government treats the spectrum like a public park. The property rights model, on the other hand, sees the spectrum as something to be owned and managed exclusively by private parties. According to this model, the FCC treats the spectrum as it would treat private land (Nuechterlein & Weiser, 239-240). Each model contains different assumptions about how the spectrum should be controlled and operated to reach its highest potential and what interests should be advanced by these uses.[13] As with all media systems, the structural attributes of spectrum management are bound up within larger political economic relationships. In this case, spectrum policy has shifted towards privatizing the public airwaves, reflecting broader shifts in the economic and political landscapes over the last several decades to market-based approaches and deregulation. This shift in the reigning regulatory paradigm has combined with the fact that, increasingly, spectrum is being used less for traditional broadcast media, and more for data communications services like cell phones and Internet access.

In turning to the private property model, it is instructive to recall that the 1927 Radio Act allowed for "the use of such [radio] channels, but not the ownership there of." This "nonownership" clause was seamlessly transferred into the 1934 Communications Act, establishing the foundation for licensure of the public airwaves. However, Ronald Coase, in his seminal 1959 article, "The Federal Communications Commission," characterized the 1927 Radio Act as a missed opportunity for asserting a property rights regime of spectrum management in which market operations would dictate allocations and assignments (Hazlett, 1990).[14] This 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 of select users with exclusive licenses. According to the "Coase Theorem," spectrum policy based on public interest grounds was fundamentally flawed. Instead, Coase believed that a clear assignment of exclusive and permanent property rights in frequencies would allow the free market to allocate resources to their most efficient use—assuming that transaction costs are kept low. Coase argued, "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] Building on this analysis, telecommunications firms and their lobbyists, industry-funded non-profit organizations, as well as many independent research institutes and academics, have fought for decades to shift spectrum licensure towards a more Coase-like private property model.

Another market-based approach, though falling short of treating the spectrum as private property, replaces the comparative hearings model by allocating spectrum to the highest bidder via auctions (Weiser and Hatfield, 2008; Hazlett, 2008). This practice became increasingly standard in the 1990s under the Clinton administration.[16] The private property approach to spectrum management generally views the market as a neutral if not benevolent arbiter of a crucial resource. Given its inherent biases towards the monetization of "public interests" (and externalization of benefits that cannot be commoditized), many critics see this approach as disproportionately benefiting powerful economic interests and privileging profit-making uses, especially given the prohibitive costs for purchasing exclusive rights to spectrum. In light of this bias, policy historians Moss and Fein (2003) provide a useful corrective to Coase's assumption that the driving concern behind the 1927 Radio Act was primarily technical and economic.[17]

Another alternative to Coase's model is posited by Benkler in his discussion of a "commons-based peer-production" model, which advocates collaboration and sharing over privatization of resources:

> Removing property and contract as the organizing principles of collaboration substantially reduces transaction costs involved in allowing…potential contributors to review and select which resources to work on, for which projects, and with which collaborators. This results in allocation gains, that increase more than proportionately with the increase in the number of individuals and resources that are part of the system (Benkler, 2002).

Benkler (2002) argues that these models use a "variety of technological and social strategies to overcome the collective action problems usually solved in managerial and market-based systems by property and contract." Moreover, the economic core of Benkler's critique holds that exclusive licensing is the economics of centralized infrastructure investment, and control by a network operator; it can do better at ensuring quality of service for its defined function, but is slow to evolve or innovate. In contrast, unlicensed spectrum sharing is the economic model of the Internet, with most control and investment decentralized to the edges of the network, which promotes more consumer choice and rapid innovation (Snider, 2006b; Zittrain, 2008). Such critiques have proliferated even as the property rights model has increased in prominence in recent years. Indeed, there are accumulating signs that commons-inclusive models are beginning to gain favor as the inefficiencies of single-use licensure become increasingly clear.[18]

Contrary to the general economic and political trends outlined above, a somewhat neglected scholarly tradition addressing the normative concerns as well as the practical benefits of sharing resources also exists. Frequently referred to as a commons-based approach to the management of communications systems, Benkler's model emphasizes cooperation and innovation as opposed to privatization and enclosure (Comstock & Butler, 2000; Hamelink, 2000; Lessig, 2001; Benkler, 2004; Benkler & Nissenbaum, 2006). For example, noting how many of the efficiencies associated with a property rights regime often constrain action, Benkler's *Wealth of Networks* lays out the benefits afforded by a commons-based policy orientation:

> Commons are another core institutional component of freedom of action in free societies, but they are structured to enable action that is not based on exclusive control over the resources necessary for action…Now that material conditions have enabled the emergence of greater scope for nonmarket action, the scope and existence of a core common infrastructure that includes the basic resources to produce and exchange information will shape the degree to which individuals will be able to act in all the ways that [are] central to the emergence of a networked information economy… (Benkler, 2006, p. 24).

Although Benkler discusses the "socio-economic system" of the commons mostly in relation to web-based peer production, many of its principles are contained in notions of dynamic spectrum utilization. These principles are typified by two key characteristics: decentralization and "the use of social cues and motivations, rather than prices or commands, to motivate and coordinate the action of participating agents" (Benkler & Nissenbaum, 2006, pp 400-403). Other proponents of the feasibility of the commons approach include Mark Cooper, who demonstrates that unlicensed spectrum sharing is ideal for optimal efficiency and collaborative production, though he also allows for a flexible, quasi-property licensed approach (Cooper, 2006).

Given that all technology is inscribed with social values that foreclose certain possibilities while encouraging others, a growing number of scholars emphasize how the emergence of new radio technologies lend themselves to a commons model via "spectrum sharing."[19] The advent of computers, innovations in transceiver technologies and digital communications have combined to produce new platforms for dynamic spectrum sharing that are more efficient and cost-effective than anything available to prior generations of spectrum users.

B. The Promise of Spectrum-Sharing

With the increasing significance of spectrum for telecommunications (ranging from satellite TV and digital radio to Blackberries and iPhones), both the costs of spectrum licenses as well as the potential social benefits[20] have increased dramatically. Advances in wireless telecommunications technology have driven the demand placed upon radio frequencies as people rely more on cell phones and Wi-Fi, and less on traditional broadcast media like terrestrial television. Changing technologies have also expanded the potential dynamism in spectrum sharing schemes according to time, direction of arrival, frequency, and the physical location based on latitude, longitude and altitude (Matheson, 2005).

The Spectrum Policy Task Force's (SPTF) "Unlicensed Devices and Experimental Licenses Working Group" proposed another method of introducing commons 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. Advances in smart or cognitive radio (CR) and software defined radio (SDR) technologies have fundamentally expanded options for spectrum use in ways that have yet to be acted upon by regulatory agencies. Traditionally, the artificial scarcity of government licenses to utilize spectrum has led to quandaries in finding frequencies to support wireless broadband Internet. However, these new developments have created opportunities for dynamic spectrum sharing, thus potentially ending the persistent problem of artificial spectrum scarcity by shifting the spectrum paradigm from static to dynamic (Werbach, 2002). This especially holds true for utilizing unused spectrum, referred to as "white spaces."

These emerging "smart" wireless technologies seem to naturally encourage a commons-based model. "Smart" and cognitive radios, for example, rapidly scan and process spectrum use in real time and identify underutilized frequencies. In essence, these systems are aware of their radio frequency (RF) environment and can adapt to changes in this electromagnetic space. Thus, within a given band, two transceivers can send data between each other, "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.

White space devices (WSDs) employ spectrum sensing technologies (so-called, "smart radios") to automatically detect occupied frequencies (Jones & Phillips, 2007). These technologies allow WSDs to identify and utilize the unassigned frequencies between broadcast television channels and outside the coverage areas of licensed broadcasters. They can utilize the unoccupied frequencies in the television bands for digital communications—including broadband networks—forming the foundation for a new communications era that incorporates advances in miniaturization and transceiver technologies to better meet consumers' needs. WSDs facilitate and improve home, business, city, community, and regional networks, enabling everything from increased rural and municipal broadband access, to enhanced public safety communications, more reliable video conferencing, and the potential for any number of future consumer applications or devices. WSDs will facilitate more affordable broadband deployment, particularly in underserved rural areas, as well as stimulate new innovations in consumer products and services. The military has been testing WSD technology for years and has run numerous tests demonstrating its feasibility as a part of the DARPA XG project. In a decisive turning point in WSD feasibility debate, in October, 2008 the FCC Office of Engineering and Technology released its report "Evaluation of Prototype TV-Band White Space Devices – Phase II," which concluded that the "proof of concept" of WSDs has been met, potentially opening a new chapter for broadband deployment and technological innovation (Shared Spectrum, 2006; FCC, 2008).

These technological developments underscore the fact that our contemporary moment marks a critical juncture in telecommunications history akin to the advent of the telephone, radio, or television. Computers and other digital technologies have enabled an entirely new communications medium – distributed, portable, "device as infrastructure" networks. Within these networks, end-user devices are "smart," capable of adapting to changing environments and maximizing efficient use of available spectrum to deliver mobile, affordable broadband connectivity. A coalition of consumer and other public interest groups, along with a number of high-tech companies, actively support the widespread adoption of these innovative new technologies.[21]

As is often the case, however, technology has outpaced regulation, and new policies are needed to end the artificial scarcity of spectrum. Unfortunately, as Nuechterlein & Weiser observe, "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…"(p. 226). Now that the scarcity rationale no longer holds, traditional spectrum management strategies are largely obsolete. "Just as the First Amendment bars the government from limiting who can own a printing press," Nuechterlein & Weiser suggest "it might well bar the government from restricting access to the airwaves as a medium of communication in the hypothesized word of super-abundant spectrum" (p.230). These arguments for expanded public access to the public's airwaves will only continue to proliferate as arguments for shoring up an outdated status quo—to the benefit of incumbent power and the detriment of everyone else—become increasingly less tenable (New America Foundation, 2005).[22]

C. A Third Way for Spectrum Reform

Our proposed model of spectrum management assumes that protecting important government services must remain a priority. Fortunately, smart technology-enabled spectrum sharing will be able to simultaneously open unused spectrum while protecting legacy uses. John Stine provides a brief synopsis of one potential solution to the problem of protecting primary (government) spectrum users, Synchronous Collision Resolution:

> The Synchronous Collision Resolution (SCR) MAC protocol enables a strict arbitration of spectrum access based on spectrum rights thus enabling a hierarchy of networks in the same spectrum that always guarantees the primary rights holder precedence. Second, it autonomously manages the use of an arbitrary number of channels in the same network all of which support the network achieving a higher capacity. The third and most exciting idea is a new Fast Command and Control model for spectrum management (Stine, 2005).

In less technical terms, technologies like SCR "arbitrate the primary and secondary use of both the channel and the network...On one extreme, the primary and secondary users may have completely isolated networks and on the other extreme primary and secondary users fully cooperate to form a single network where access rights transfer with packets" (Stine, 2005). Furthermore, since the spectrum management scenarios can be built into the software of radio devices, they can be dynamically shifted (for example, to opportunistically reuse existing networking infrastructure during a natural disaster).

SCR is only one option out of many for ensuring that primary spectrum users maintain precedence over specific bands while allowing additional users to opportunistically reuse what would otherwise go to waste. In much the same way that the Unlicensed National Information Infrastructure devices (U-NII) in the 5GHz radio band are shared by military radar and unlicensed 802.11a Wi-Fi devices, additional government bands can be shared using new technologies. Within the U-NII band, the FCC found that "the existing operations include Government radiolocation systems; mobile satellite feeder links; amateur operations; industrial, scientific, and medical operations; other unlicensed Part 15 operations; and proposed ITS," and yet still agreed that sharing primary and secondary use was both feasible and desirable. The FCC also determined that it would "allow U-NII devices in this band to operate on a technology-neutral basis," stating that "We believe this will provide manufacturers flexibility in designing U-NII products and thus will provide consumers with greater choices" (FCC, 199, Paragraph 72).

It should be noted that there are well-founded concerns about interference and other potential drawbacks with spectrum sharing schemes. As Weiser and Hatfield sum up, "the FCC should continue moving ahead to implement different proactive and reactive measures that will provide users of commons access spectrum with important assurances that new services and products will not be compromised either by bad actors or poor coordination" (p. 132). Today, there are new technologies in development to further increase spectral efficiency and protections for primary users. Additionally, there are ample regulatory precedents for sharing spectrum among primary government and private users and secondary unlicensed users. The most efficient spectrum sharing regimes will make use of networks of cognitive (smart) radios to maximize spectral density and minimize interference. According to Weiser and Hatfield, "Two notable examples of such [spectrally efficient] technologies are 'spread spectrum' and 'cognitive radios,' both of which can be used to avoid creating large 'white spaces' (i.e., unused or underused bands) in the spectrum" (p. 109). Similarly, Cooper describes the technological foundations for spectrum-sharing hardware:

> An agile radio is a software-defined radio, one that can change its use of frequencies, power, and modulation without changing its hardware. In this sense, it is agile – as it can move around the spectrum. Frequency agile radios are a subset of the broader category, which can be agile in other dimensions (power and perhaps wave form). An agile, software defined radio is the basic building block of the new communications network. Adding sensors and a reasoning system to an agile radio gives us a cognitive, intelligent, or smart radio. Cognitive radios are aware. They sense the network and store the rules of the road. Embedded logical systems allow them to decide when to transmit without breaking the law. Cognitive radios can be combined into systems. The cognitive system adds a layer of intelligence to the communications network by looking at the overall topography of the network (2006, p.20).

Research into multi-tier networks has been a growing field of inquiry in recent years. Chandrasekhar and Andrews (2008) posit that "a decentralized spectrum allocation strategy as an alternative to centralized/coordinated frequency assignment in a two-tier network" can dramatically increase area spectral efficiency and network capacity. Another group of researchers conducted an in-depth analysis of opportunistic spectrum access and found that "The Open Spectrum approach to spectrum access can achieve near-optimal utilization by allowing devices to sense and utilize available spectrum opportunistically." Through their analyses, proofs, and simulations, they demonstrate that a distributed system "provides benefits comparable to the centralized approach while drastically reducing computation complexity." Though only an initial foray into this new realm of opportunistic spectrum reuse, they reached the same conclusion as Cooper: opportunistic reuse of spectrum is itself optimized through the use of non-centralized (ad-hoc) networking systems (Peng, Zheng, and Zhao, 2006).

Grokop and Tse (2008) address the issue of sharing spectrum among different wireless networks and discover that there is a natural, game theory-based rational for cooperating among many wireless networks. Accordingly, they demonstrated that the Nash Equilibrium was often attainable, even among rival networks and "that contrary to ones intuition, there can be a natural incentive for devices to cooperate to the extent that each occupies only a fraction of the available bandwidth. Such results are optimistic and encouraging. We suspect it may be possible to extend them to more complex operating protocols such as those that employ carrier-sensing to determine when the medium is free."[23] In addition to technical feasibility, previous research suggests that the economic model for unlicensed sharing affords compelling advantages: low barriers to entry, low transaction costs, and flexible, decentralized investment at the edges of the network.

Altogether, whether one looks at the game theory, technological underpinnings, RF environment simulations, or mathematical proofs, as Cooper summarizes, "the predominant opinion is that information sharing and cooperation will greatly improve the management of the spectrum commons" (2006, p. 24). Since the spectrum commons provides far better spectral efficiency than command and control infrastructures, spectrum regulators must ensure that the necessary transitions are made as new technologies become available to achieve these efficiencies. Given that government agencies have already taken the lead in this area, and given the precedent they already set to encourage spectrum sharing, opportunistic spectrum reuse of federal bands is a natural place to increase access to the public airwaves.

IV. IMPLICATIONS & POLICY RECOMMENDATIONS

In our view, the roll out of new spectrum-sharing technologies holds profound implications for the future of telecommunications networks. Even based on the relatively limited data available, there appears to be an abundance of underutilized spectrum that could be shared with a wide-range of important services. Indeed, the NTIA's Spectrum Plan report states that sharing is both feasible and desirable, even if implementation plans are vague. Increasingly, policymakers are entertaining a model of spectrum sharing. Therefore, it is time to begin discussing what this sharing scheme should look like. In the following, we offer a set of recommendations for developing a sharing plan based on opportunistic unlicensed use (i.e., one that is not monetized), and is based on publicly available and easily accessible data on current usage. New spectrum-sharing technologies and new capacities for spectrum usage require new policies that exploit technological opportunities to the greatest democratic potential. Given the available data, our analysis leads us to the following recommendations:

Recommendation 1: Share Spectrum Instead of Leaving it Underutilized

By most measurements, current usage of the spectrum is nowhere near full capacity. As noted above, during the 2004 RNC convention in New York City—when one would expect the local frequencies to be at peak usage—it was found that only a relatively minuscule amount of spectrum was being use (McHenry, 2004). Currently there is an incentive for incumbents to squat on vacant spectrum instead of sharing it. Since the marginal costs of simply adding new users are nearly non-existent, the main barriers to moving forward with implementation are the education of decision-makers and the political will to push federal agencies to share their spectrum with the general public on a secondary basis.

Recommendation 2: Share Spectrum Before Auctioning

Revenues of spectrum auctions have not meaningfully impacted the general public. J.H. Snider, for example, estimates that while the U. S. has nominally established a spectrum auction system, this system has distributed public assets for only 10 percent of its value (Snider, 2007).[24] Instead of auctioning spectrum, a more ideal solution would have individual federal agencies incentivized to share their spectrum. The fact that the military agreed to share its radar band without monetary compensation provides us with a powerful precedent. In particular, we do not advocate for metering or other schemes for monetizing underutilized spectrum since doing so would create additional barriers to entry as well as transaction costs, and thus fail to usher in a new and diverse set of spectrum users.

Recommendation 3: Share Spectrum Instead of Reallocation

New technologies like smart radios adapt to dynamic scenarios where multiple users can share the same spectrum and hop frequencies as necessary. Moreover, multiple sharing strategies are possible, based on time division, angles of antennae, and geolocations of transceivers. Sharing is much easier than having incumbents, such as federal agencies, migrate to other bands—a process that is both time consuming and costly. By this measure, dynamically sharing instead of reallocating spectrum better ensures the realization of more efficient spectrum management paradigms.

Recommendation 4: Share With Secondary Users While Protecting Federal Primary Use

Government agencies may have regular, intermittent, or extraordinary need for their allocated spectrum. As such, a general regulation supporting shared use of government bands should maintain primary use for the agency to whom the specific frequencies are allocated. Accordingly, opportunistic unlicensed use would be secondary to agency needs. There are numerous technological solutions that will ensure the primacy of government use while supporting unlicensed reuse of available frequencies. Therefore, regulations should be technologically neutral and certification of devices should focus on ensuring that primary uses are protected. Because different manufacturers may choose to implement different solutions for opportunistic spectrum reuse, information on spectrum use (e.g., modulations, frequencies, reception sensitivities of equipment to out of band emissions, etc.) by government agencies must be provided so that proper certification criteria can be drawn up for each band. Bands should be viewed as modular elements so that consumer equipment manufacturers may choose to support the use of specific frequencies depending upon the technical specifications and certification criteria provided. Government prioritization would be integrated into contention protocols in devices utilizing shared spectrum.

Recommendation 5: Reserve Repurposed Spectrum for Unlicensed Use

Sharing federal spectrum should be reserved for unlicensed use for a number of compelling reasons. Keeping spectrum unlicensed optimizes flexibility for critical ad hoc operations such as emergencies and natural disasters, as well as creative deployments of new technologies. While traditional licensure creates a significant barrier to entry and facilitates massive inefficiencies in spectrum use, smart technologies render such licensure unnecessary.

Recommendation 6: Make Federal Spectrum Data Publicly Available Online

The U.S. should follow the lead of other countries and make information on federal allocations more widely accessible. Making allowances that certain security-related information should remain classified, it is imperative that this information become accessible so that agencies as well as non-federal entities may see usage patterns to base key decisions on where sharing spectrum is feasible. Presently, according to the Spectrum Plan, this information is recorded in the Government Master File (Spectrum Plan, p. 3). External pressures brought to bear on the NTIA would likely bolster internal efforts to free up this crucial information. Moreover, the new Obama administration should welcome this greater transparency. The Democratic Party has made this goal explicit in their 2008 platform, vowing to "create a new 'open source' government, using technology to make government more transparent, accountable and inclusive," requiring that "agencies conduct significant business in public and release all relevant information unless an agency reasonably foresees harm to a protected interest." They also promise to "make government data available online [via] an online video archive of significant agency meetings" to "enhance the flow of information between citizens and government…by involving the public in the work of government agencies" (Democratic Platform Committee). Assuming these officially stated goals are more than election year rhetoric, such gestures are positive steps toward engaging the public, whose participation is necessary for reforming U.S. spectrum policy. Passing the recent Radio Spectrum Inventory Act sponsored by Senators Kerry, Snow, Nelson and Wicker is a first step in the right direction.[25]

V. CONCLUSIONS AND FUTURE INQUIRY

This study is still a preliminary attempt to begin a broader discussion regarding a grossly underutilized resource that has escaped much scrutiny. Policy decisions that open up government spectrum for opportunistic unlicensed reuse have the potential to essentially eliminate spectrum scarcity in the United States. Among many other social benefits, such as creating jobs and providing for public safety, this revitalization of the public airwaves would help establish desperately needed communications infrastructure, bring affordable internet services to underserved areas, and reverse America's sub-optimal state of broadband penetration (Peha, 2008; Weiser, 2008). The technologies that can enable commons-based spectrum management have arrived. All that prevents these much-needed spectrum management reforms is a lack of political impetus. Whereas sufficient political will among policymakers is presently lacking, the recent rise of a public interest bloc pushing for unlicensed use of television white spaces gives hope that a similar focus could arise around federal white spaces. Indeed, we argue that the recent DTV white space debate is merely the tip of the iceberg. We hope that our analysis can serve as a small step toward kick-starting a much-needed discussion about the future of U.S. federal spectrum policy.

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ENDNOTES

[1] In cases like the citizens' band (CB) spectrum is set aside for amateur use, or according to "Part 15" rules which allow some public wireless devices such as garage door openers and microwave ovens to operate in unlicensed spectrum
[2] For a Government Accountability Office overview of IRAC, see GAO-0401028. IRAC Representatives Effectively Coordinate Federal Spectrum but Lack Seniority to Advise on Contentious Policy Issues. September, 2004.
[3] There are sixty nine federal agencies and departments who use radio frequency spectrum for communications, navigation, broadcasting, and other uses.
[4] There are some exceptions where government agencies share frequencies and networks. For example, NTIA literature notes that the USDA runs a National Interagency Fire Center where emergency replies can be utilized during emergencies and the Treasury Department operates a "Federal Commons" as an interoperable frequency assignment to be shared among all Federal agencies for law enforcement and coordination with state and local police during emergencies. See Federal Strategic Spectrum Plan, p. 3.
[5] For example, recommendation #7 called for "spot compliance checks and signal measurement surveys to verify the accuracy of the records of the Government Master File (GMF), identify congestion and instances of duplicative operations that could be combined, and evaluate the utility of underutilized spectrum. NTIA should use the results of these reviews in the development of new and improved spectrum management policies, and the Federal Strategic Spectrum Plan." See http://www.ntia.doc.gov/reports/specpolini/presspecpolini_report1_06242004.htm and see also http://www.ntia.doc.gov/reports/specpolini/presspecpolini_report2_06242004.htm
[6] The CSMAC "advises the Assistant Secretary of Commerce for Communications and Information at NTIA on a broad range of issues regarding spectrum policy and on needed reforms to domestic spectrum policies and management to enable timely implementation of evolving spectrum-dependent technologies and services to benefit the public. The members are spectrum policy experts, appointed as 'Special Government Employees' from the private sector and balanced in terms of their points of view. Committee members offer expertise and perspective on reforms to enable new technologies and services, including reforms that expedite the American public's access to broadband services, public safety, digital television, and long-range spectrum planning." The CSMAC held its first meeting in 2006. See http://www.ntia.doc.gov/advisory/spectrum/
[7] An example of some of the most detailed information made available by NTIA can be seen in a nearly decade-old Office of Spectrum Management report, "Federal Long-Range Spectrum Plan, http://www.ntia.doc.gov/osmhome/LRSP/Final-LRSP.pdf
[8] As of August 2008, the NTIA's spectrum chart was dated October 2003 and does not include numerous changes to spectrum allocations that have happened in ensuing years.
[9] For an overview, see the new CED chart: www.cedmagazine.com/WorkArea/downloadasset.aspx?id=157960
[10] Under the DOD's spectrum requirements, it describes its strategy as a "Network Centric Architecture Vision" that consists of "autonomous, self-healing, ad hoc networks, producing a shared information environment." Elsewhere it notes that "SDRs programmed with rules will dominate the future battlefield." See Spectrum Plan, B-174
[11] The report includes spectrum information from the following groups: Broadcasting Board of Governors, Department of Agriculture, Commerce, Defense, Energy, Homeland Security, Interior, Justice, State, Transportation, Treasury, Veterans Affairs, National Aeronautics and Space Administration, National Science Foundation, Tennessee Valley Authority, U.S. Coast Guard, U.S. Postal Service.
[12] See, for example, the following reports submitted to the FCC: http://www.nella.org/jra/dr/katrina/jeff-allen-talk.pdf. The full report is located at the following: http://www.nella.org/jra/dr/katrina/katrina-final-report.html. See also the following comments supporting ad hoc networking:http://www.mediaaccess.org/file_download/164
[13] It should be noted that hybrid models and other alternatives are also emerging as well. The Spectrum Policy Task Force reached a conclusion that a mix of flexibly-licensed spectrum and unlicensed spectrum is superior. For an economic case for unlicensed use of white spaces, see Pierre de Vries, "Populating the Vacant Channels," New America Foundation Working Paper, 2006. http://www.newamerica.net/publications/policy/populating_the_vacant_channels
[14] Proponents of Coase tend to be more focused on the private market with respect to assignments primarily – the equivalent of real property lots – and less so on allocations – the equivalent of zoning (which is pre-assignment). 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, which aimed to codify broadcasters' public service responsibilities. The key for Coase vis-à-vis efficiency is that the initial assignment of rights is unambiguous, which is why "property" in the electromagnetic

properties of the atmosphere – which is very technology dependent – is more problematic than Thomas Hazlett concedes, especially when they are fluctuating based on the parameters that make a frequency variously "white."

[16] Other market-oriented reforms dictated that personal communication services and secondary markets were operated in ways that treated spectrum as private property. The past few years have witnessed a renewed call for further privatization of spectrum. Although Hazlett differs with Weiser and Hatfield regarding potential drawbacks, these leading spectrum researchers 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. Weiser & Hatfield have explained how the core Coaseian presumption of clearly defined and stable property rights is not typically true with spectrum (as it is with real estate).. See also, Michael Calabrese, NAF Working Paper "Principles of Spectrum Reform,"2001. He made the important point that the electromagnetic properties of the atmosphere are not anything like real property. Cementing the banding (zoning) plan developed for analog technologies into permanent property boundaries could be the equivalent, in a digital world, of requiring that residential lots be sold only in round plots.

[17] Moss and Fein demonstrate that, in fact, officials were less concerned about devising an economically efficient means of allocating scarce spectrum and much more concerned about preventing monopoly markets and the concentration of political power. By privileging democratic principles over economic concerns, at least some government officials involved in the policy debates aimed to create a diversity of voices on the airwaves. Nevertheless, such normative concerns have been largely stripped from the property rights model of spectrum management.

[18] For example, real time micro-auctioning/micro-payments is a potential hybrid approach – allowing both for primary licensure and the opportunistic reuse of underutilized spectrum by third parties.

[19] For an online resource that provides ample materials promoting "open spectrum" see http://openspectrum.info/

[20] For example, consumers have a preference for variety as well as quality. Licensing can not unilaterally dominate the commons apporach in terms of consumer surplus. In spectrum environments that are not inherently noisy/prone to interference, and when consumers have a preference for variety, the commons has the potential to create more consumer surplus. See E. Bayrak "Welfare Effects of Spectrum Management Regimes," *in Proc. of the 3rd IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks*, Oct. 2008. Also see Bayrak, Ergin. 2008 "Valuing Time Intensive Goods: An Application to the Wireless and Wired Internet," *mimeo*, Department of Economics, University of Southern California, where the author found consumer surplus that accrues to consumers who connect to the internet through Wi-Fi home networks is at least $824 per household per year more than the consumer surplus of wired network users. As a result Wi-Fi home networking alone (among many other users of unlicensed spectrum) creates considerable consumer surplus, and can be a lower bound on the consumer surplus of unlicensed spectrum. Assuming about 30 million Wi-Fi home network users, the total consumer surplus could easily reach $25 billion.

[21] For a list of the coalition members, see Wireless Innovation Alliance: http://www.wirelessinnovationalliance.com/ (last visited December, 12, 2008).

[22] 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 (e.g., Fargo, N.D.).

[23] A Nash Equilibrium is where every actor believes they have made the best decision taking into account others' decisions. This is not always the ideal situation, as in the case of business cartels.

[24] There are exceptions for certain categories, like public safety and terrestrial broadcasting.

[25] For a good analysis of this bill, see Harold Feld, "Kerry-Snowe Spectrum Inventory Bill: A Good Starting Point For Licensed And Unlicensed Supporters" March 26, 2009. http://www.publicknowledge.org/node/2056.