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Reclaiming the Vast Wasteland

THE ECONOMIC CASE FOR RE-ALLOCATING THE UNUSED SPECTRUM (WHITE SPACE) BETWEEN TV CHANNELS 2 AND 51 TO UNLICENSED SERVICE

By J.H. Snider*

On May 12, 2004, the FCC issued a Notice of Proposed Rulemaking (NPRM) proposing unlicensed use of unused TV channels 2-to-51 (Docket 04-186). When the DTV transition ends in early 2009, most of the nation's 210 TV markets will have between 10 and 40 unassigned channels reserved for broadcasting, but not in use. The FCC proposal would allow a new generation of wireless broadband devices to utilize the vacant TV channels in each local market for WiFi and other unlicensed technologies.

Although incumbent TV broadcast license holders and their vendors opposed the NPRM, leading high-tech companies, including Intel and Microsoft, came out strongly in favor and submitted compelling technical evidence that unlicensed devices could be introduced into the unoccupied TV guard bands without causing harmful interference to TV reception on neighboring licensed channels. Although broadcast interests have succeeded in lobbying FCC Chairman Kevin Martin to stall a final FCC decision, there is increasing bipartisan interest in Congress in opening these wasted frequencies for unlicensed wireless networking. On February 17, Sen. Ted Stevens, Chairman of the Senate Commerce Committee, and a bipartisan foursome of Committee members (Sens. Allen, Sununu, Kerry and Boxer) introduced legislation ordering the FCC to complete the rulemaking and to open unused TV band spectrum for unlicensed devices. This would particularly benefit rural and small town areas where wired broadband is unavailable or unaffordable.

This summary of my longer Working Paper is structured in four sections, preceded by some brief background about why a majority of the DTV frequencies are unoccupied. Section I argues that the white space should be reallocated from broadcast to broadband use. Section II explains the technological and economic forces behind the shift from licensed to unlicensed use. Sections III and IV provides an overview of the economic and non-economic arguments for unlicensed use, respectively.

Background

The broadcast TV band is famously underutilized, mostly because of the large number of vacant TV channels[1] known as "guard bands" (alternately known as "white space" or "taboo channels") that have historically served as an interference buffer between local analog TV stations, protecting them from harmful interference. With analog TV technology, for example, if channel 15 is used in one market, then channels 14 and 16 cannot be used in the same market and channel 15 also cannot be used in adjacent, surrounding markets. But just as air conditioning technology made the Southwest into prime real estate, digital technology is transforming the TV guard band spectrum into prime spectrum real estate. Indeed, one of the major debates of the digital TV (DTV) transition concerns how access to this so-called TV band "white space" will be reallocated. Because this spectrum is worth billions of dollars, it's in the TV broadcast industry's interest to keep others out of the white space and gradually win free access to it for itself.

How much vacant TV band spectrum is available around the country? There are 210 local TV markets in the United States. Each is currently allocated 67 channels (channels 2-to-69, excluding channel 37, which is reserved for radio astronomy and medical telemetry). The FCC's current TV allocation plan mandates that after the DTV transition, channels 52-to-69 will be cleared of TV signals in all 210 local TV markets in the United States. Four of these channels are being reallocated for public safety agencies, while ten others will be auctioned for exclusive, licensed use by commercial wireless firms. In February 2009, at the end of the digital TV transition, broadcasters must give back one of their two channels. However, even after channels 52-to-69 are returned, substantial guard band spectrum will remain, especially in small TV markets, on the 49 channels from channels 2-to-51. This has fueled debate about what to do with those freed up channels.

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At the conclusion of the DTV transition, the average TV market will have only approximately seven high-power channels in operation (a high-power channel is one that covers its entire market, whereas a low-power one may only cover a small fraction of the market). Since large markets such as New York City have many more high-power stations than small markets such as Burlington, Vermont, the population weighted average number of channels per market is higher, approximately 13 stations.[2]

In either case, the ratio of unused to used channels is high—more than five to one. It is no wonder that many have called the TV band spectrum a "vast wasteland" of underutilized spectrum.[3] The share of the DTV band that is available for wireless broadband services ranges from roughly a third in relatively congested markets (e.g., Dallas and Boston) to more than two-thirds in small town and rural markets (e.g., Fargo and Juneau). See Table 1.[4]

Table 1 – 'White Space' as a Share of TV Band in Sample of U.S. Media Markets

Market	Post-DTV Transition	
	No. of Vacant Channels Between 2-51	Percent of TV Band Spectrum Vacant
Juneau, Alaska	37	74%
Honolulu, Hawaii	31	62%
Phoenix, Ariz.	22	44%
Charleston, W.V.	36	72%
Helena, Mont.	31	62%
Boston, Mass.	19	38%
Jackson, Miss.	30	60%
Fargo, N.D.	41	82%
Dallas-Ft. Worth, Tex.	20	40%
San Francisco, Calif.	19	37%
Portland, Maine	33	66%
Tallahassee, Fla.	31	62%
Portland, Ore.	29	58%
Seattle, Wash.	26	52%
Las Vegas, Nev.	26	52%
Trenton, N.J.	15	30%
Richmond, Va.	32	64%
Omaha, Neb.	26	52%
Manchester, N.H.	23	46%
Little Rock, Ark.	30	60%
Columbia, S.C.	35	70%
Baton Rouge, La.	22	44%

These freed up channels are considered to be most appropriate for shared, unlicensed use because they will not be contiguous either nationally or regionally. For example, an unused channel in Baltimore may be in use in the adjacent markets of Washington, DC and Philadelphia.

Until recently, it was thought that non-contiguous spectrum allocations would have very little economic value—just like 40 scattered quarter-acre real estate parcels may be less valuable for commercial development than a contiguous ten-acre lot. Why would a manufacturer want to produce a wireless device that couldn't be used nationally? How would it be possible to make a portable radio device that would work in Baltimore on a particular channel but wouldn't work in Philadelphia on the same channel, even if transported there? Accordingly, the Swiss cheese pattern of guard band channels generated relatively little commercial interest.

However, the technological environment has rapidly changed. The advent of low-power "smart radios"—which can sense their spectrum environment and avoid interference with licensed transmissions—dramatically increase the ability of localized wireless broadband operators to efficiently utilize non-contiguous spectrum. Consumer advocates and high-tech companies, including Intel and Microsoft, argue that such "smart radios" are the perfect application for this Swiss cheese guard band spectrum. In response, the FCC issued its NPRM proposing unlicensed use of unused TV channels 2-to-51, subject to strict equipment certification requirements to avoid harmful interference with DTV reception.

The broadcasters have fought tooth and nail to oppose this use of the guard band white space. Publicly, they have argued that unlicensed use of this spectrum will cause intolerable interference with existing TV stations, thus slowing down the DTV transition and perhaps even rendering all over-the-air television unusable. Behind the scenes, they have sought to win free access to this guard band spectrum for themselves. Indeed, in addition to delaying the return of their second channel, many local TV station licensees have been allowed to expand their coverage areas, thus eating into the guard band spectrum in adjacent markets despite the fact that fewer than 15% of American households rely on over-the-air reception—a number that will steadily decline toward zero as Internet television and other options become readily available.

Two companion papers issued by the New America Foundation respond to the broadcast lobby's interference claims.[5] Briefly, these papers argue that the broadcasters' technical comments are without merit, and call attention to the broadcasters' below-the-public-radar strategy to win free rights to white space, including the unpublicized transfer of $6 billion worth of TV guard band spectrum to broadcast industry licensees since 1997. Holding up competing uses of spectrum until the government eventually gives up and allocates all the spectrum rights to local TV broadcasters is a clever lobbying strategy. But it's not one that Congress and the FCC should reward.

I. Broadcast to Broadband: Low Frequencies are Far More Valuable for Mobile Broadband Services

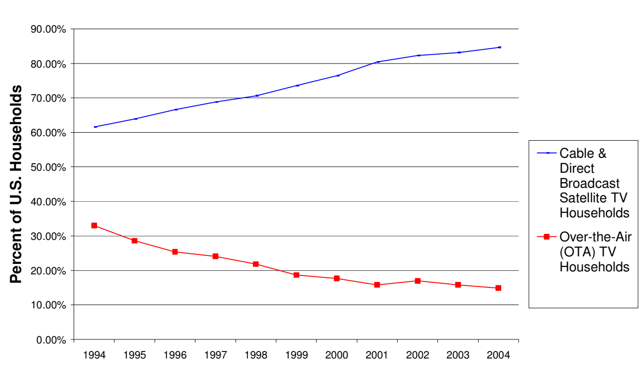
Since the mid-1980s, prominent telecom policy analysts have been arguing that broadcasting is a misuse of low-frequency spectrum. In the mid-1980s, Nicholas Negroponte, founder of the MIT Media Lab, popularized a view that became known as the Negroponte Switch: the idea that stationary services (such as broadcast TV) should use wires; and mobile services (such as talking while driving or roaming within your house) should use the airwaves.[6] At the same time, the FCC initiated a proceeding—later defeated by the National Association of Broadcasters (NAB) on the grounds the spectrum would be needed to transition to HDTV—to reallocate 168 MHz of unused broadcast spectrum to non-broadcast services.[7]

In 1990, George Gilder wrote a book titled *The Death of Television*, which elaborated on this basic idea that conventional broadcast TV was a great misuse of spectrum.[8] Since then, there have been dozens of telecom analysts who have made much the same argument.[9]

The two underlying economic reasons why over-the-air (OTA) TV broadcasting is a misuse of low-frequency spectrum are fairly simple. First, over-the-air broadcasting has close yet superior substitutes. Both satellite and cable TV can provide the same programming as local broadcast TV but with more reliable signal quality (e.g., hills and buildings don't degrade images), greater geographic coverage (in the case of satellite, the entire continental U.S.), and more programming choice (as many as 100 times more channels of the same resolution). This reality has resulted in the continuing decline in demand for over-the-air broadcast TV. From 1970 to 2005, the percentage of US television households relying exclusively on over-the-air reception for their TV has declined from essentially 100% to less than 13%,[10] with a drop of about 14 percentage points coming in the last decade alone.[11] This drop is remarkable, since it occurred despite huge government subsidies to preserve over-the-air TV and despite the fact that an additional fee is required to view identical local broadcast TV programming over cable or satellite systems. So far, the figures for *digital* over-the-air TV are even more dismal. As of 2004, 40.4% of Americans had access to digital TV but only 2.7% of those relied on broadcast DTV. The rest relied on cable DTV (50.7%) and satellite DTV (46.6%).[12]

This is not to say that over-the-air broadcasting does not retain a niche, especially among households with low demand for TV, or for those who cannot get either satellite or cable service for some reason. However, this niche is getting smaller for fundamental technological and economic reasons. Figure 1 depicts the decline of terrestrial over-the-air TV and the rise of cable and satellite TV.

***Figure 1*– The Decline of Over-the-Air Television**



Sources: NCTA, SBCA, FCC, Census

Second, the opportunity cost of continuing to use low-frequency spectrum for broadcasting has become increasingly evident. The demand for broadband Internet services is skyrocketing. Americans want high-speed anywhere/anytime/anything information services, which conventional digital broadcasting cannot deliver but which the low-frequency spectrum broadcasters occupy is ideally suited to provide. This is reflected in the fact that companies do not purchase expensive licenses to access low-frequency spectrum today to provide conventional, fixed broadcast TV services, digital or otherwise; for this type of spectrum, the market values mobile, interactive, Internet-based information services.

The economics favoring low-frequency spectrum for non-broadcast services is based on the physical characteristics of the spectrum. Low-frequency spectrum is better suited for mobility because its waves are longer and can thus better pass through objects such as walls, foliage and weather.[13] All terrestrial mobile telephone services, for example, are located below 3 GHz (the lowest 1% of the radio spectrum). If cell phone service went out every time someone passed a tree or building, its utility would be minimal. Similarly, WiFi service would be much less valuable if it couldn't pass through walls, furniture, people and other common household obstructions. And, indeed, the cost and quality of wireless broadband deployments would improve dramatically, as noted below, if networks and devices could operate below 1 GHz, where TV operates today.

Higher-frequency spectrum is primarily used for line-of-sight applications, such as a direct connection between a satellite and a home satellite dish, or for a point-to-point microwave link used as a backhaul between a building rooftop and a fiber node several miles away that is linked to the Internet backbone. The primary reason that a license to use a given amount of high-frequency spectrum sells for much less than a license to use a comparable amount of low-frequency spectrum is that a high-frequency license must compete with close substitutes from wired services. Instead of using a point-to-point microwave link, for example, a company can use an optical fiber link and get the same or better service. In contrast, there are no wired substitutes for mobile services, such as cell phones.

Another major physical advantage of low-frequency spectrum is that it requires less energy than high-frequency spectrum to cover the same distance. The large waves that characterize low-frequency spectrum lose less energy when they pass through objects. As a result, they can cover greater distances with the same power. This, in turn, means that battery-powered devices can be less expensive, longer-lived, smaller and lighter. In the emerging era of ubiquitous, portable wireless devices, this can be a great advantage.

Lastly, lower-frequency devices require fewer cell towers or access points (for meshed networks)—and hence substantially lower infrastructure costs—to cover a given geographic area. This is a corollary of the power observation above. If power is held constant, then coverage is enhanced with lower-frequency spectrum. This savings in expense for towers and access points is especially important in rural areas where broadband service is less constrained by the amount of spectrum and more constrained by the cost of additional antennas or higher towers to reach residents. An Intel study estimates that a rural wireless network transmitting on the 700 MHz TV band can cover four times the area, and at a higher quality of service, than a network transmitting at 2.5 GHz.[14] Assuming that the capital cost of towers and access points are the fundamental constraint on rural broadband deployment, low-frequency spectrum for broadband can reduce rural broadband deployment costs by 75% or more.

II. Licensed to Unlicensed: Economic Trends and Spectrum Efficiency Favor Low-Power, Networked Devices

When household, business and government entities consider low-power wireless applications, they have increasingly come to the conclusion that unlicensed spectrum offers them service at lower cost and higher quality than licensed spectrum. Already, millions of American households and businesses use unlicensed WiFi technology—a remarkable feat for a product that only became generally available six years ago. In addition, thousands of wireless Internet service providers (WISPs) use unlicensed frequencies to provide wireless Internet services to more than 500,000 homes, schools and businesses, primarily in rural areas where wired broadband connections are unavailable or unaffordable. And, more recently, dozens of towns, cities and counties have announced plans to rely on unlicensed frequencies to blanket their entire jurisdiction with pervasive connectivity. Given that the FCC and Congress have strongly favored licensed products in the amount and quality of spectrum they have allocated, this evolution is all the more remarkable.

What explains the shift from licensed to unlicensed spectrum services? FCC and industry observers have long agreed that it would be inefficient for the Federal government to sell toll booth rights to third parties to collect payments from individuals who use low-power wireless consumer devices—including cordless phones, baby monitors and garage door openers—on their own property. The same economic logic is being played out with spectrum rights for wireless broadband networking. For many good reasons, the world is moving toward networks of low-power devices, such as household WiFi, enterprise WiFi, municipal WiFi and highway WiFi. Forcing households, enterprises and local governments to purchase spectrum rights from a third-party license holder for strictly localized, low-power uses of spectrum needlessly adds cost and often reduces quality of service. Imagine if citizens needed to pay CBS or Verizon to operate a cordless phone or garage door opener. Where it's not necessary to enable a service or avoid harmful interference, imposing a spectrum intermediary through licensing is a Federal government mandate that acts, in effect, like a hidden tax.

Unlicensed devices are generally found in four types of locations: homes, workplaces (including offices, hospitals,

Figure 3 - Sampling of Wide-Area Unlicensed Networks

Manufacturing, Distribution, and Inventory Management
Biggs' Hypermarket, Mason and Harrison, Ohio
Nine Mile Point Nuclear Station
Nike, Memphis, Tennessee

Universities
Dartmouth College, Hanover, NH
Carnegie Mellon University, Pittsburgh, PA
United States Military Academy, West Point, NY

Hotels (all with Free WiFi)
Best Western
Courtyard (Marriott International Inc.)
Doubletree Hotels (Hilton Hotels)

Hospitals
Baycrest Centre for Geriatric Care, Toronto, Canada
Children's Memorial Hospital, Chicago, Illinois
John C. Lincoln Hospital, Phoenix, Arizona

K12 Schools
Lincoln Unified School District, Stockton, California
Arlington Independent School District, Arlington, Texas
Fairfax County Public Schools, Fairfax, Virginia (available in more than 200 schools)

Retail
ALLTEL Stadium, Jacksonville, Florida (host of 2005 SuperBowl)
Barnes & Noble Bookstores, hundreds of locations
Starbucks, thousands of locations

Municipal, Outdoor Public Safety
Lower Valley Public Safety Network, Yakima County, Washington
City of Aurora Police and Fire Departments, Aurora, Colorado
City of San Mateo Police Department, San Mateo, California

Municipalities, Outdoor Public Access
Philadelphia, Pennsylvania (planned)
Corpus Christi, Texas
Chaska, Minnesota

Convention and Sports Centers
American Airlines Center, Dallas, Texas
Connecticut Convention Center, Hartford, Connecticut
William A. Egan Civic and Convention Center, Anchorage, Alaska

Airlines (only international travel)
Lufthansa
Japan Airlines
Korean Air

Airports
Atlanta International Airport, Atlanta, Georgia
Baltimore-Washington International Airport
Boston, Logan International Airport, Boston, Massachusetts

Other
Marinas (Beacon WiFi supplies WiFi service to more than 100 boat marinas)
RV Parks, (Boingo supplies WiFi service to hundreds of RV parks)
Flying J truck stops (hundreds of locations)

college campuses and warehouses), retail establishments (including coffee shops, hotels, libraries and airports), and public rights of way (including municipal roads, highways and subways). As Figure 3 suggests, a growing variety of private and public sector institutions are deploying wide area wireless broadband networks on *un*licensed frequencies.

Most important from a policy perspective, unlicensed devices can either be low power or high power. It takes more energy to transmit over larger distances, so—all other things being equal—lower-power devices cover a smaller geographic area than higher-power devices. FCC-approved lower-power unlicensed devices usually focus their energy within the property lines of a particular entity. An example of a small-area device would be a WiFi router covering a home; an example of a large-area device would be a cell tower covering a square mile.

A basic rule of thumb in spectrum allocation is that unlicensed spectrum is more efficient for low-power, small-area devices (including networks of small area devices that collectively cover large areas), while licensed spectrum is more efficient for higher-power, large-area devices (such as broadcasting). Even advocates of licensed spectrum have been extremely careful not to explicitly argue in public that they should be allowed to take possession of spectrum rights within property contour lines. Instead, they have sought to divert attention with misleading claims related to potential interference, enforcement problems and tragedies of the commons.[15] It is therefore of great significance for spectrum policy that emerging economic forces strongly favor the use of low-frequency, small-area devices as a substitute for low-frequency, large-area devices.

Small-area devices can be networked together to cover a wider area, usually still focused within the property lines of a particular entity, such as a college campus. Thus, there are two types of unlicensed large-area networks: one type comprised of high-powered devices and the other type comprised of many low-power devices meshed together. Failure to recognize this distinction between the two types of large-area unlicensed networks has been the source of great public confusion and chicanery by advocates of more licensed spectrum. It is typically the basis on which they create a straw man argument that unlicensed service cannot provide large-area coverage without chaos stemming from a "tragedy of the commons"—the mismanagement of a free resource that becomes degraded through overuse. But, as we shall see, this argument reflects a profound misunderstanding of the growing importance and ubiquity of networked small-area devices.

Consider municipal WiFi, the fastest growing and most high-profile type of low-powered wide area network.[16] These unlicensed networks can traverse great distances via public roads and other public rights of way. For example, Philadelphia's plan to build a franchised municipal WiFi system will network some 8,000 access points to cover the entire 135-square-mile footprint of the city.[17] And the Canamex highway WiFi network in Arizona may cover more than 500 miles before it is complete.[18]

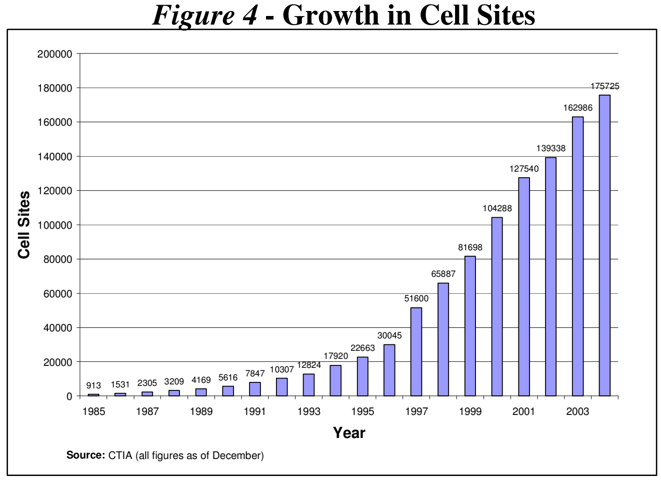
Tens of thousands of other large spaces, including college campuses, hospitals, malls, warehouses, stadiums, K-12 schools, amusement parks and office buildings, have been building networks of small-area devices that collectively cover large areas. Similarly, thousands of Wireless Internet Service Providers (WISPs) have been providing unlicensed coverage to households and businesses in rural areas where the signal passes through a lightly populated area, often in a focused beam.

The Shift to Lower-Power Wireless Devices in the Lower Frequencies

During the early years of radio, the most prominent terrestrial wireless services tended to send signals over great distances. Moreover, they used single, relatively high-power devices to do so. At the beginning of the 20th century, for example, the most famous demonstration of radio's utility was a terrestrial transmission across the Atlantic Ocean from England to the United States—essentially a high-powered shout over an enormous distance. Later, TV and radio broadcasters typically used a single transmission tower to cover thousands of square miles. Early cell phone companies, too, typically covered many square miles with a single transmitter. Today, the economics of wireless communication favors low-power transmissions on frequencies with greater penetration and carrying capacities.

One major economic force leading to the growth in terrestrial low-power wireless communications is that high-power wireless service has close wired substitutes—but mobility does not. Over time, optical fiber is moving closer and closer to the premises. Optical fiber is relatively expensive to deploy but is otherwise a superior technology to wireless for backhaul—that is, linking small-area networks to the Internet backbone. Fiber's capacity is huge, and it has excellent quality of service. For example, a single strand of optical fiber has more information carrying capacity in a direct point-to-point communication than the entire radio spectrum. For this reason, the major telephone companies and cable operators are planning to bring high-speed fiber lines to the neighborhood and eventually to the premises in every high-density area in the United States.

Figure 4 **- Growth in Cell Sites**



Nevertheless, wireless communication remains a highly valued complement to wired communication. For these reasons of both quality and cost, the long-term economic logic of the terrestrial communications system is to bring wires as close as possible to the home and business, but leave the last part of the communications link wireless. As wired communication nears the individual, it loses its quality advantage because it cannot provide anytime, anywhere (i.e., mobile) service. As wires approach the individual, their cost advantage also tends to diminish. For example, the cost of digging a trench on a major city street can be shared by tens of thousands of customers; that is, it has great economies of scale. But by the time the wire gets to the premises, the cost of laying the wire can only be shared by the relatively small number of people at the wire's destination.

A second major economic force leading to lower-power devices is the growing opportunity cost of large wireless cell sites. Just as demand for Internet backbone capacity is skyrocketing, so is demand for spectrum capacity. People want faster, higher fidelity, interactive communications and they don't want to have to be plugged in to access it. At the same time, the supply of spectrum is fixed. Carriers can purchase rights to use additional spectrum. But since the supply of spectrum is not infinite, this ultimately means robbing Peter to pay Paul.

The long-term strategy, then, must be to expand the information carrying capacity of spectrum, especially low-frequency spectrum. Carriers can do this by employing more efficient data compression technology or developing more advanced modulation technologies to squeeze more bits of information on a single electromagnetic wave. Such strategies are useful as far as they go, but they are strictly limited.

> *"Just as air conditioning technology made the Southwest into prime real estate, digital technology is transforming the TV guard band spectrum into prime spectrum real estate."*

The most efficient long-term strategy to increase the information carrying capacity of spectrum is to geographically subdivide it so that it can be reused in different geographic areas. Since each cell can reuse spectrum, the information capacity of a cellular network is directly proportional to the number of cells. A carrier can increase capacity by acquiring additional spectrum—or by investing more capital in spectrum efficiency. ArrayComm CEO Martin Cooper has estimated that more than 97.5% of the increase in spectrum capacity since 1960 has come from reducing the geographic coverage area of cells.[19] Vividly demonstrating the diminishing size of cells, New York City recently leased out its 18,000 light posts, each a potential cell site for up to a half-dozen wireless vendors. See Figure 4 for the growth of cell towers. This growth has largely been driven by the need to subdivide cells to increase information capacity. Another way to subdivide geographic coverage is with directional antennas that point signals in a specific direction and thus can reuse spectrum in different directions.

The extent of this dilemma is illustrated by today's mobile telephone services. Even the most advanced services are currently struggling to provide 1 Mbps of mobile service. For example, the Verizon Wireless 3G service (called "EV-DO") only provides *mobile* broadband users up to 700 kbps—and that is under highly optimistic conditions. To provide service at 10 Mbps, 100 Mbps, or more, Verizon Wireless would have to migrate to ever smaller cell sizes, which helps explain the demand for wireless sites on New York City's light posts. With mobile telephone service or today's typical broadband services, higher speeds may not be critical. But as Americans spend ever increasing amounts of time on the Internet accessing ever higher-bandwidth applications, the demand for spectrum bandwidth will continue to skyrocket, requiring ever shrinking geographic coverage.

Now consider this thought experiment that highlights the underlying economic logic. Assume that the cost of a low-power wireless transmitter drops to zero while demand for bandwidth increases to infinity. The economic equilibrium derived from such assumptions would be an infinite number of infinitesimal cell sites.

Of course, these assumptions, as stated, are unrealistic. The cost for wireless transmitters will not drop to zero, and the demand for bandwidth will not grow infinitely. However, the cost of factory-ordered WiFi chips has already dropped to $5/each in high-volume purchases and that number could drop to pennies within a few years. Fry's Electronics already sells a WiFi access point at retail for $19.95. In contrast, a high-power TV transmitter may still cost over $1 million. Meanwhile, Verizon, Comcast and others are already building wired networks to homes and businesses with a planned capacity of 100 mbps or more. Using today's conventional state-of-the-art mobile telephone cell architecture, even the allocation of all low-frequency spectrum would not be enough if the thousands of households within a cell must all share the same spectrum and expect to receive 100 Mbps wireless service. Thus, although these assumptions are unrealistic, they do highlight a fundamental economic force driving cell architecture.

Another advantage of low power is less battery usage. As portable devices grow in popularity, efficient battery use grows in importance. Physics dictates that the greater the distance a wireless device must send its signal, the greater the power it must use as well as the corresponding size, weight and cost of batteries.[20] Low power also opens up the possibility of solar-powered WiFi, which is useful for a host of military, scientific and municipal applications, as well as in disaster relief, developing countries and remote rural areas, where there is unreliable or no electricity.[21]

Similarly, physics dictates that the amount of energy required to send information is a function of the number of bits sent. Every additional bit requires more energy. When telephone-quality audio bits are the predominant type of bits sent, power usage is relatively low. But as we move into a world of CD-quality voice communication, interactive video, and other high bandwidth applications, hundreds of times more power may be needed. When the bits are coming from a battery-operated portable device, this becomes a major problem. One way to address it is with lower-power links between the transmitter and receiver.

Another advantage of lower power is more comprehensive coverage. The conventional wisdom is that pervasive computing and communications requires a high-power wireless network. But, in fact, the opposite is the case. Wide-area networks tend to miss many spaces blocked by impenetrable barriers such as hills, buildings, and elevator shafts. Mobile telephone service, for example, is frequently unavailable within commercial buildings and homes, especially in low-density areas. That's why major commercial buildings and underground public transportation systems often have their own very small local area cells.[22] J.D. Power calculates that 3 out of 100 cell phone calls has a quality of service problem.[23] But it doesn't calculate the much greater number of calls that aren't made because people have learned not to expect service.

Another advantage of lower power is more precise coverage. Let's say a local government wants to cover its public spaces, including the public roads that link every house and business in its territory. Low-power allows it to do this without interfering with other, nearby low-power users unless those users seek access to its network. Many municipal WiFi networks, for example, are designed in default mode to focus their coverage within public rights-of-way.

Another advantage of low power is greater security. Wired communications are more secure than wireless communications because of the confined space in which they operate; it's necessary to dig up a wire to intercept a shielded, buried wired communications link. But the last wireless leg of a communications link is relatively easy to intercept with any device in its coverage area. Thus, the smaller the coverage area—for example, a corporate campus vs. an entire city—the more secure the connection.

All this analysis does not deny that there are economic advantages to large cell sites, most notably the higher capital costs associated with more cell sites. This economic logic is most striking in rural areas that are range limited rather than capacity limited. In rural areas, cells cover large distances but few people, so there isn't enough demand to justify subdividing cells. For example, only in such areas does WiMax's boast of providing 70 Mbps of service over a radius of 30 miles make any sense. In a dense urban area like New York City, the same WiMax transmitter would only provide a trickle of service—perhaps at an even lower speed than a dialup modem—and probably miss the vast majority of people due to the obstruction of large buildings.

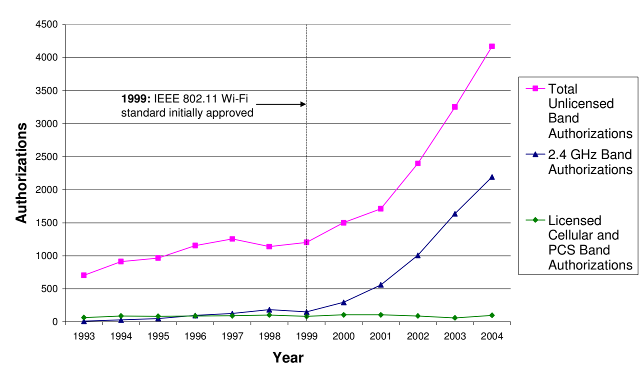
Consequently, rural areas with low population density will continue to have larger cell sizes than urban areas with high population density. But as the demand for wireless information soars and the cost of low-power wireless equipment plummets, the economic tradeoffs between low-power and high-power devices—even in rural areas—shift decisively to the advantage of low power.

Links Between Low-Power Devices, Unlicensed Spectrum and Economic Efficiency

The essence of unlicensed spectrum is decentralized, local control of spectrum rights. Confidence is placed in local property owners and communities to figure out how best to use their spectrum rather than the Federal government, which is ill equipped to determine the needs of tens of millions of homeowners, millions of businesses, and tens of thousands of municipalities. It turns out that this local control has many beneficial economic consequences in terms of increased innovation, lower costs and higher-quality service. To the extent that the Federal government has allowed such local control, it has been embraced by homeowners, businesses, and local governments on the demand side, and by venture capitalists, entrepreneurs and manufacturers on the supply side.

Figure 5 compares the growth in devices manufactured to operate on unlicensed spectrum with mobile telephone authorizations for licensed cellular and PCS bands. Observe that the unlicensed 2.4 GHz band—the largest unlicensed band in the prime low-frequency spectrum below 3 GHz—has more than 25 times the number of authorizations as the mobile telephone bands. This is despite the fact that the mobile telephone bands occupy far more spectrum (more than twice as much) and far better spectrum (the unlicensed 2.4 GHz band has both a higher frequency than the mobile telephone bands and is nicknamed the "junk" band because unlicensed devices must accept interference from a host of other devices that use that band, including licensed devices and dumb, non-telecommunications emitters such as microwave ovens).

Figure 5 **– FCC Device Authorizations for Licensed and Unlicensed Bands, 1993-4004**



Source: Carter, Kenneth, *et al., "Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues,"* FCC, May 2003; FCC OET Equipment Authorization Program Database.

Also note that most of the unlicensed growth has occurred since 1999. That growth is primarily attributable to the development of smart unlicensed devices, such as WiFi, in the 2.4 GHz band. Previously, dumb unlicensed devices such as garage door openers dominated the unlicensed market. It is also noteworthy that unlicensed devices, like licensed devices, are overwhelmingly located in the low frequencies. At these frequencies, the equipment is cheaper, can be positioned without regard to physical obstacles like walls and uses less battery power.

III. Economic Advantages of Unlicensed Spectrum

Now let's look more closely at the economic advantages of unlicensed spectrum.

Lower Barriers to Entry for Manufacturers. For manufacturers of wireless products, unlicensed spectrum has lower barriers to entry, leading to more competition and innovation. With licensed technology such as mobile telephone service or public safety communications, entrepreneurs must first purchase a license or get permission from a license holder before launching their innovation. This creates a number of problems. Many manufacturers consider securing rights to use licensed spectrum from private parties as comparable in difficulty to getting rights to use spectrum from the FCC. Like government license holders, private license holders may create huge bureaucratic obstacles before granting permission to use their spectrum, and the outcome may be highly uncertain. In the high-tech world, a delay of six months in getting a product to market can be the difference between success and failure.

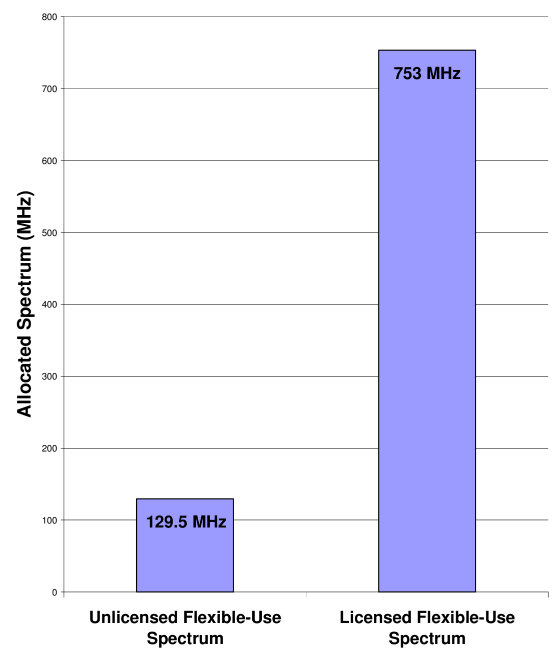
Many licensed bands employ proprietary technologies with large license fees that discriminate against small companies. For example, license fees to use W-CDMA, a popular cellular telephone standard, may be 30% of the total product cost for a small manufacturer but as little as zero percent for a large manufacturer with more negotiating power and its own patents to barter.[24] When small players have to pay a 30% premium for the same product, it discourages innovation. WiFi is an open standard, so is not burdened by such royalty payments.

Entrepreneurs also worry about holdup problems and uncompensated appropriation of their ideas. In addition to a royalty, the licensee may insist on a cut in the profits of any successful innovation and may choose to compete with the entrepreneur if the innovation proves especially lucrative. Consider Ibiquity, the new digital radio standard for the AM and FM bands. The large commercial radio broadcasters insisted that they get a fee for any radio device sold using spectrum where they had a license. Thus, they banded together to create a company, Ibiquity, that would develop an exclusive proprietary standard for their spectrum band. The commercial broadcasters were genuinely interested in studying other companies' proposed radio standards. But the bottom line was that if the technology used their spectrum, they wanted control of it—a demand that would discourage many entrepreneurs.

In seeking negotiating leverage, a spectrum license holder may also reveal the idea to competitors, thus eliminating the entrepreneur's first mover advantage. In fast moving high tech markets, this advantage is often critical to profitability.

As a case study on the influence of licensing barriers to entry on market structure, compare the level of competition and innovation in the mobile telephone and unlicensed bands in the prime spectrum below 3 GHz. The mobile telephone band is a good reference case because that is where the most licensed spectrum activity takes place. In addition, the mobile telephone bands will shortly control at least five times as much spectrum as the unlicensed bands (See Figure 6).[25]

Figure 6 **– Licensed vs. Unlicensed Flexible Spectrum Under 3 GHz**



Sources: Kobb, Bennett, *Wireless Spectrum Finder* (2001), FCC, Legg Mason, 47CFR §25.2

As in many other licensed bands, no mobile telephone handset manufacturer can sell a product within a particular band without first getting permission from the licensed carrier in that band. Getting such permission usually involves developing a unique model for the licensed carrier and selling it through the licensed carrier's approved retail channel. As a result of these and other economic incentives, fewer than ten handset makers, including Nokia, Motorola, Samsung, Sony Ericcson, and LG, control 99% of the U.S. retail handset market.

In contrast, there are hundreds and perhaps thousands of manufacturers now selling unlicensed devices, despite the fact that the mobile telephone industry is more than two decades old and the new industry of smart, unlicensed devices barely five years old. These companies include Dell, Scientific Atlanta, Intel, HP, Linksys, D-Link, Panasonic, Sony, Starkey Laboratories, Kodak, Canon, Nikon, Sony, Microsoft, Hexagram, Sharper Image, Nortel, Cisco, Motorola, Toyota, BMW, Zensys A/S, Logitech, Connexion, Lumin, Tropos, BelAir, Ember, Chipcon, Freescale, Vocera, Avaya, Colubris, Spectralink, CardioNet, Crossbow Technology, General Electric, Palm, Nintendo, and Honeywell.

A major reason these companies exist is that they sell highly differentiated products targeted at narrow market niches. Indeed, the public has never heard of most of these companies precisely because they are targeted to such narrow market niches. Consider the mobile video surveillance system developed by ODF Optronics, an Israeli company. The product consists of a ball that a public safety official (e.g., police, fire, military) can throw into a building and on a remote screen monitor a 360-degree view of the room. The entire worldwide market for this product may be tiny compared to the market for a mobile telephone handset. But that doesn't mean the product isn't extremely valuable and capable of saving many lives.

> *"Why should a home or business pay Verizon Wireless $60 per month per individual for wireless data service when its premise is already linked to high-speed wired service and can add a wireless component for zero dollars?"*

Lower Barriers to Entry for Carriers. Just as there are lower barriers to entry for manufacturers, there are lower barriers to entry for carriers. Unlike wide area networks, there are minimal economies of scale in local area networks. This is true whether the networks are wired or wireless. Again, contrast mobile telephone and unlicensed markets. Mobile telephone service is dominated by just four carriers: Verizon Wireless, Cingular, Sprint Nextel, and T Mobile. In contrast, thousands of carriers have emerged in the unlicensed space in the US alone. These include between 4,000 and 6,000 WISPs providing WiFi service to mostly rural areas;[26] more than 85 municipal and regional governments providing WiFi networks for public use and/or government and public safety agency use (with at least 34 more networks planned or under construction);[27] and more than 20,000 coffee shops, airports, truck stops, and many other retail businesses in America.[28] (See Figure 3 above for a sampling of carriers.)

Lower Usage Costs for End Users. An increasing number of household, business, and government entities have access to wired broadband connections via DSL, cable and fiber. When these entities look for wireless service on or near their premises, unlicensed usually becomes the obvious low cost solution. For example, why should a home or business pay Verizon Wireless $60 per month per individual (plus about 15% in taxes) for wireless data service when its premise is already linked to high speed wired service and can add a wireless component for zero dollars per month per individual?

The cost of extending a wired connection to anyone in or near the premise—using unlicensed spectrum—is the one-time cost of an off-the-shelf wireless router (as little as $30 to unwire a home). This logic largely explains the significant pressure on mobile telephone carriers to introduce dual mode handsets that can carry both licensed and unlicensed communications. The carriers hate this idea because up to 40% of the minutes used by their customers are made in household and business premises where WiFi is likely to be used.[29] In addition, there is the threat that free or low cost WiFi will be strung on more roads, thus depriving mobile telephone companies of their bread and butter revenue. WiFi networks are also open networks whereas mobile telephone networks are mostly closed, which means that mobile telephone operators would be likely to lose content and transaction revenues that they can currently monopolize.

Finally, American carriers have been especially resistant to genuinely open dual handsets because more than 50% of the mobile telephone market is controlled by two operators, Cingular and Verizon, which also have wired networks. When consumers switch to WiFi calls, the operators will not only lose toll minutes on their wireless networks but also toll minutes on their wired networks. Still, the business pressure is becoming so great that dual mode WiFi phones are expected to become widespread within the next few years.

Lower Equipment Costs. A number of factors have led unlicensed equipment to have lower equipment costs than most licensed equipment. These include lower royalty rates and greater economies of scale. Unlicensed chips are designed for flexible use and mass consumer markets, so are relatively inexpensive even if installed in a highly specialized product. Contrast, for example, the cost of public safety and WiFi equipment. A Motorola public safety phone costs in the vicinity of $3,000 whereas a WiFi access point with comparable technological sophistication costs only about 1% of that, or $30. Most of the difference is simply due to economies of scale. Municipalities deploying mobile public safety networks on unlicensed spectrum frequently cite equipment cost as one key reason.[30]

For mobile telephone technology, the production economies of scale are comparable to WiFi. But the equipment costs for entities larger than a household tend to be much greater. This is because of the need to install redundant equipment from multiple carriers. Many markets have four to six mobile telephone carriers. To get ubiquitous in-building coverage for all potential licensed users, an entity needs to install equipment from each of these vendors. This may be cost effective for large, heavily trafficked entities such as sports stadiums and malls. But for smaller entities, such as the vast majority of businesses and local governments in the U.S., standardizing on a single WiFi standard may be more efficient.

Higher Quality for End Users. In real world applications, unlicensed spectrum has many quality advantages over licensed mobile telephone spectrum. These are the same advantages leading to the growth of low-power devices, and include better coverage, faster speeds (due to more efficient use of spectrum), smaller devices (due to less need for power and smaller batteries), more security and higher quality of service. Consequently, the most demanding wireless users, notably large, sophisticated businesses, are shifting to unlicensed for reasons of quality as well as cost.

A major advantage of unlicensed spectrum for business is greater control, including tight integration with corporate PBXs, which are widely perceived to allow for better transferring, parking, monitoring and filtering of calls than mobile telephone networks. Businesses are increasingly seeking to have on-premise mobile employees, and they want those employees to be able to carry their work and use the same PBX features, including internal extension numbers, wherever they go. With WiFi, they can do this whether the employee is working at the corporate campus, telecommuting from home, or working out of a hotel. This is especially important in businesses, including hospitals, hotels, warehouses, retail stores and universities, where a large fraction of employees are constantly moving around.

Businesses also want more control over quality of service. A large fraction of mobile telephone calls are dropped. When the CEO of a major corporation is making a wireless call to a vital client, he doesn't want the call dropped because a teenager two miles away is chatting with his girlfriend. The mobile telephone company doesn't offer him a way to ensure his call gets through. But through integration of a VOIP WiFi phone into his PBX, he can do that.

Businesses also want more control of internal security. Both licensed and unlicensed wireless devices now have similar encryption technology to prevent unauthorized access to information. But high-power out-of-building mobile telephone signals are much more vulnerable to hackers and corporate espionage.

Businesses also want more control of coverage. Only a small percentage of businesses have complete on-premise mobile telephone coverage. Elevators, basements, nearby buildings, steel or concrete walls, and factory machines are just a few of the obstacles that typically pose barriers to ubiquitous coverage.

Businesses also want high speeds where they need it. Security, medical and warehouse personnel may have a need for high speed images and video on the go. For example, a doctor in an emergency room may highly value the ability to download a patient MRI sixty times faster via an unlicensed (WiFi) than a licensed (mobile telephone) network. Indeed, the extra speed may be the difference between life and death for a patient.

Facilitating Innovation. Many products and services wouldn't even exist without unlicensed spectrum. Today, the vast majority of wireless products are only manufactured to use unlicensed spectrum. For example, the Sony Portable Playstation video game player, the Kodak EasyShare digital camera and the Dell Axim personal digital assistant have built in WiFi to connect to the Internet but no mobile telephone links. The reason is obvious. Manufacturers can include a WiFi chip for about $5/device, users don't have to pay usage charges and the speed of connection is faster. Embedding a mobile telephone in one of these products is possible, but in practice has proven prohibitively expensive for most consumer markets.

IV. Non-Economic Arguments

This paper has focused on the economic arguments for unlicensed spectrum. But there are also First Amendment, universal service, public safety and takings clause arguments for unlicensed spectrum.

First Amendment. Spectrum is the 21st century's essential medium for speech—and not merely to passively receive information, as citizens do vis-à-vis broadcasting, but to create and communicate in a world of pervasive connectivity. Open access and decentralized control of this medium fosters robust free speech, a fundamental value long recognized in the United States for its economic and democratic value. Along these lines, it is revealing that one of the best indicators of whether a country supports unlicensed use of spectrum is whether it is a dictatorship. The 15 countries in the world that require a license to use WiFi are Bahrain, Belarus, China, Cuba, Democratic Republic of the Congo, Kazakhstan, Macau, Mongolia, Myanmar, Oman, Pakistan, Sri Lanka, Ukraine, Vietnam, and Zimbabwe.[31] Every European and North American country allows unlicensed WiFi.

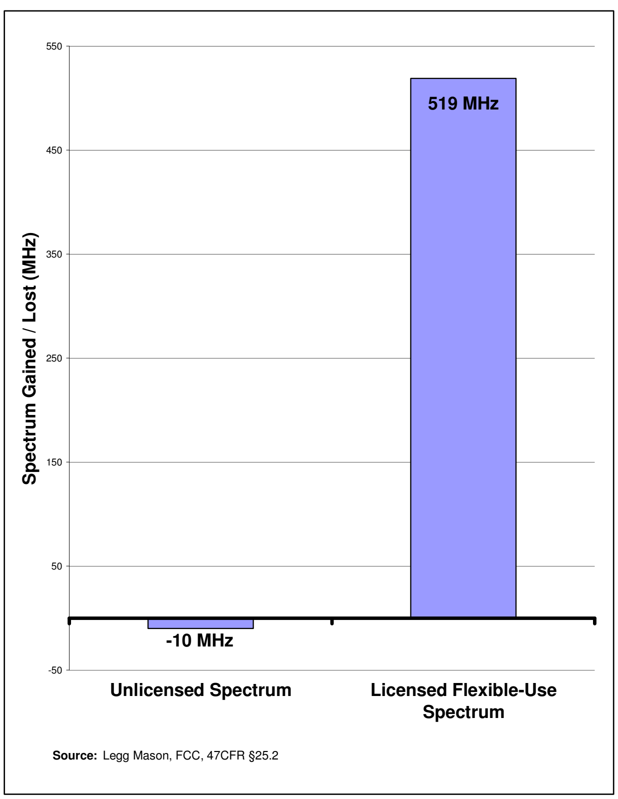
Universal Service. America is now 16th in the world in broadband penetration.[32] Low-frequency, unlicensed spectrum is critical to bringing affordable broadband services to poor, under-served communities. This is a major factor explaining the explosion in both urban (municipal) and rural (WISP) WiFi deployments. The low-cost, high-quality calculus of unlicensed spectrum has proven to be an unbeatable formula for bridging the broadband divide. For example, Philadelphia's WiFi franchisee, Earthlink, plans to offer broadband service to low income households for $10/month, less than 25% of the cost of the broadband service offered by its cable franchisee, Comcast.

Public Safety. A rapidly growing number of municipal and county public safety agencies are using unlicensed spectrum to build out high-speed mobile data networks, despite the fact that they have free access to licensed spectrum.[33] First responders are driven to use unlicensed spectrum for four primary reasons. First, real world public safety agencies have limited budgets. Second, unlicensed equipment is less expensive, primarily because it is mass produced for all market segments, not just public safety. Third, telecommunications is a fixed cost business, so sharing infrastructure costs across multiple market segments reduces the costs any one market segment must pay. Fourth, numerous public safety products are only designed to use unlicensed spectrum, primarily because many public safety equipment entrepreneurs have recognized there is no net advantage to using licensed spectrum. Insofar as unlicensed spectrum results in more public safety services being purchased on a limited budget, unlicensed spectrum results in more lives saved, which are presumably priceless.

Takings Clause. Allowing the Federal government to take control of local spectrum rights—use of the airwaves within private homes and business establishments—via a tacit form of eminent domain (that is no less consequential because it deals with the invisible airwaves rather than real property) and then give away those rights to a handful of the largest and most politically powerful companies in the U.S. (albeit in the name of "deregulation," "spectrum flexibility," "investment certainty," and other Orwellian claims) should be an outrage to all Americans because it is a taking of their property without just compensation.

Of course, "property rights" to electromagnetic spectrum must be tempered by free speech and anti-monopoly considerations. We don't allow local governments to unduly control acoustic speech on public property (imagine the outrage if a local government banned people from freely talking with each other while using public property such as a street or park!). Similarly, we should not allow local governments excessive control of electromagnetic speech.

Figure 7 **– Reallocations of Spectrum Below 3 GHz Since November 2002 FCC Spectrum Policy Task force Report**



The same principle applies to private property. For example, the FCC's over-the-air reception device (OTARD) rules prevent a landlord from regulating access to the airwaves and extracting a monopoly rent from a tenant for installing a relatively inconspicuous antenna to pick up a signal. This principle should also apply to unlicensed devices.

Conclusion

This paper has argued that the best use of the TV guard band white space is for unlicensed broadband services. Driving the analysis are the unique propagation characteristics of the low-frequency TV band and the growing economic importance of low-frequency, low-power spectrum applications, as exemplified by the rapid growth of home WiFi, enterprise WiFi and municipal WiFi.

Obviously, there continues to be an economic case for terrestrial broadcast and licensed spectrum. However, that case is getting weaker while the economic case for broadband unlicensed spectrum is getting stronger.

The policy implication of this analysis is that a new balance must be struck between the allocation of licensed and unlicensed spectrum. Specifically, the balance should be shifted to favor unlicensed spectrum—especially in the most valuable lower-frequency spectrum. In fact, spectrum policy has done just the opposite. It has extended the duration of licenses and dramatically shifted spectrum allocation in favor of licensed use. See Figure 7.[34]

In the context of the digital TV transition, the choice Congress and the FCC now face is even simpler: 1) warehouse the unused guard bands, or 2) make them available for public use. These frequencies are the crown jewel of the information age. They should be put to good use. The moment has come to stop wasting them in what amounts to one of the great economic tragedies of our times.

Endnotes

[1] Also described as "taboo channels."

[2] Thomas W. Hazlett, "The Wireless Craze: An Essay on Airwave Allocation Policy," *Harvard Journal of Law and Technology* (Spring 2001).

[3] Mark Lewyn, "Airwave Wars," *Business Week*, 23 July 1990.

[4] Table taken from "Measuring the TV 'White Space' Available for Unlicensed Wireless Broadband," New America Foundation and FreePress, January 5, 2006. Available at: http://www.newamerica.net/index.cfm?pg=article&DocID=2713.

[5] For a discussion of the broadcasters' technical arguments, *see* Michael J. Marcus, Paul Kolozy and Andrew Lippman, "Why Unlicensed Use of the White Space in the TV Bands Will Not Cause Interference to DTV Viewers," New America Foundation, Wireless Future Program Issue Brief #17, October 2005. For a discussion of the history of broadcast-industry attempts at securing access to guard band channels for themselves, *see* J.H. Snider, "Myth vs. Facts: A Response to Broadcast Industry Misinformation Concerning Possible Interference from 'Smart' Wi-Fi Devices Using Vacant TV Channels," New America Foundation Fact Sheet, September 2005, and *Speak*

Softly and Carry a Big Stick: How Local TV Broadcasters Exert Political Power (iUniverse, 2005), Appendix D.

[6] Stewart Brand, *The Media Lab: Inventing the Future at MIT* (New York, N.Y.: Viking, 1987), Nicholas Negroponte, *Being Digital*, 1st ed. (New York: Knopf, 1995).

[7] This is described at length in Joel Brinkley, *Defining Vision: The Battle for the Future of Television*, 1st U.S. ed. (New York: Harcourt Brace, 1997).

[8] George F. Gilder, *Life after Television* (Knoxville, Tenn.: Whittle Direct Books, 1990).

[9] E.g., Thomas W. Hazlett, "The U.S. Digital TV Transition: Time to Toss the Negroponte Switch," (Washington, DC: AEI-Brookings Joint Center for Regulatory Studies, 2001), Bruce M. Owen, *The Internet Challenge to Television* (Cambridge, Mass.: Harvard University Press, 1999), Snider, *Speak Softly and Carry a Big Stick: How Local TV Broadcasters Exert Political Power*. Craig Moffett, "Cable and Satellite: Search Versus Browse," in *Bernstein Research Call* (New York City: Sanford C. Bernstein & Co., 14 July 2005).

[10] *See* "Comments of the Consumer Electronics Association," FCC Media Bureau Docket 04-210, Inquiry Into Over-the-Air Broadcast Television Viewers, August 2004, p.2.

[11] *See* FCC *Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming*, "Eleventh Annual Report" (February 2005), Table B-1 and "Sixth Annual Report" (January 2000), Table C-1. Household OTA penetration is calculated as the percentage of households without MVPD service.

[12] "OECD Communications Outlook 2005," (Paris, France: OECD Publishing, 2005), p. 222.

[13] *See* Remarks of Ed Thomas, "DTV 201: How the DTV Transition Can Move the Nation from Broadcast to Broadband," New America Foundation & House Future of American Media Caucus Luncheon, September 7, 2005. Available at:

http://www.newamerica.net/Download_Docs/pdfs/Doc_File_2547_1.pdf.

[14] Masud Kibria and Chris Knudsen, "Capital Expenditure Implications of Spectrum Assets in Semi-Rural Environments," Intel Corporation Report, 4 August 2005.

[15] E.g, *see* William J. Baumol and Dorothy Robyn, *Toward an Evolutionary Regime for Spectrum Governance* (Washington, DC: AEI-Brookings Joint Center for Regulatory Studies, 2006).

[16] E.g., *see* Jesse Drucker et al., "Google's Wireless Plan Underscores Threat to Telecom," *Wall Street Journal*, 3 October 2005, p. A1.

[17] *See* "Wireless Philadelphia™ Business Plan," Wireless Philadelphia Executive Committee, February 2005, p.12.

[18] Eliot Cole, "Wi-Fi the Highway," Mobile Government, June 2005, pp. 22-25.

[19] *See* "Cooper's Law" at www.arraycomm.com. See also J.M. Vanderau et al., "A Technological Rationale to Use Higher Wireless Frequencies," (Washington, DC: U.S. Department of Commerce, February 1998), p. 10, and Toru Otsu et al., "Network Architecture for Mobile Communications Systems Beyond IMT-2000," *IEEE Personal Communications*, October 2001, p. 33.

[20] *Supra* Note 12.

[21] E.g., *see* Lumin Innovative Products at http://www.luminip.com.

[22] E.g., *see* FCC Tenth Report in the Matter of the Annual Report and Analysis of Competitive Market Conditions With Respect To Commercial Mobile Services, WT Docket No. 05-71, released 30 September 2005, p. 51.

[23] Dan Meyer, "Operators Make Call-Quality Gains in J.D. Power Study," *RCRWireless*, 8 August 2005, p. 13.

[24] Mike Dano, "Royalties Remain an Industry Mystery," *RCRWireless*, 12 August 2005, p. 1.

[25] Licensed mobile telephone bands included in this chart are WCS (2305-2320 MHz, 2345-2360 MHz); former government bands transferred to commercial use (1390-1395 MHz, 1432-1435 MHz); the Crown Castle band (1670-1675 MHz); Response TV (217-218 MHz, 219-220 MHz); CMRS (220-222 MHz), Broadband PCS (1850-1915 MHz, 1930-1995 MHz); Narrowband PCS (901-902 MHz, 930-931 MHz, 940-941 MHz); Cellular (824-849 MHz, 869-894 MHz); ESMR (817-824 MHz, 862-869 MHz); AWS (1710-1755 MHz, 1915-1920 MHz, 1995-2000 MHz, 2020-2025 MHz, 2110-2155 MHz, 2155-2175 MHz, 2175-2180 MHz); Ancillary Terrestrial Use of the MSS band (2000-2020 MHz, 2180-2200 MHz, 1626.5-1660.5 MHz, 1525-1559 MHz, 1610-1615.5 MHz, 1621.35-1626.5 MHz, 2487.5-2493 MHz), ITFS/MDS rebanding (2495-2690 MHz); and TV band auction spectrum (698-710 MHz, 722-740 MHz, 747-762 MHz, 777-792 MHz).

Unlicensed bands included in this chart are the 900 MHz band (902-928 MHz) and 2.4 GHz band (2400-2483.5 MHz).

[26] Research in late 2004 by the Wireless Internet Service Provider Association (WISPA) found that there are between 4000 and 6000 WISPs in the United States, serving between 1.5 and 2 million customers. *See* Wireless Internet Service Provider Association (WISPA) comments to FCC in Public Notice 04-163, September 28, 2004. WISPA surveyed the leading suppliers of equipment used by WISPs to find out their customer numbers. Accounting for overlap (WISPs that buy equipment for more than one supplier), WISPA estimated that there are 4000-6000 WISPs in the US. Customer estimates were made by surveying customer premise equipment (CPE) manufacturers for numbers of CPE units sold.

[27] Esme Vos, "Muniwireless.com Second Anniversary Report," July 2005, pp.1,5. Available at:

http://muniwireless.com/reports/docs/July2005report.pdf. For an up-to-date mapping of current and planned municipal and regional wireless networks, *see*

http://news.com.com/Municipal+broadband+and+wireless+projects+map/2009-1034_3-5690287.html.

[28] "2005 Telecommunications Market Review and Forecast" (Arlington, Virginia: Telecommunications Industry Association, 2005), p. 165.

[29] "Mobile and Fixed Services," *Information Week*, 10 October 2005.

[30] *See* "Wireless Public Safety Data Networks Operating on Unlicensed Airwaves: Overview and Profiles," New America Foundation Policy Backgrounder, 21 February 2006.

[31] Robert Horvitz, "Preliminary Results of the Open Spectrum Foundation's Global Survey of WiFi Regulations," Unpublished Paper, September 2005. For more information, see http://www.openspectrum.info.

[32] International Telecommunication Union (ITU) statistics, available at: http://www.itu.int/osg/spu/newslog/ITUs+New+Broadband+Statistics+For+1+January+2005.aspx.

[33] *Supra* Note 29.

[34] Licensed Mobile Telephone spectrum additions since 2002 include AWS (1710-1755 MHz, 1915-1920 MHz, 1995-2000 MHz, 2020-2025 MHz, 2110-2155 MHz, 2155-2175 MHz, 2175-2180 MHz); PCS Expansion (1910-1915 MHz, 1990-1995 MHz); Ancillary Terrestrial Use of the MSS band (2000-2020 MHz, 2180-2200 MHz, 1626.5-1660.5 MHz, 1525-1559 MHz, 1610-1615.5 MHz, 1621.35-1626.5 MHz, 2487.5-2493 MHz), ITFS/MDS rebanding (2495-2690 MHz); and TV band auction spectrum (698-710 MHz, 722-740 MHz, 747-762 MHz, 777-792 MHz).

Note that MSS providers still must provide a satellite service in addition to any terrestrial service they might choose to provide.

The FCC has reclaimed 10 MHz of unlicensed spectrum from the Unlicensed PCS band (1910-1920 MHz).