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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*

The broadcast TV band is famously underutilized largely because of the large number of vacant guard band TV channels[1] that have historically served as an interference buffer between local TV stations. 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 this so-called TV band "white space" will be divvied up. 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. This Working Paper argues that it's in the public's interest for the white space to be reallocated in accord with what we now know to be the most productive economic use of this band: unlicensed wireless broadband service.

Guard band spectrum has historically been the buffer between local broadcast 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. How much guard band spectrum is there? There are 210 local TV markets in the United States. Each is currently allocated 67 channels (channels 2 to 69, excluding channel 37 for radio astronomy and medical telemetry). Of these, the average market only uses approximately seven high-power channels (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 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]

Digital technology allows many of these guard bands to be used. For example, during the DTV transition, each existing broadcaster has been loaned a second channel so it can simultaneously operate an analog and digital channel. At the end of the digital TV transition, broadcasters must give back one of their two channels. This has fueled debate about what to do with those freed up channels.

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Broadcasters have already laid claim to some of the guard band spectrum separate from the loaned channel they must return to the public after the digital TV (DTV) transition. For example, as part of the DTV transition, many local TV stations have been allowed to expand their coverage areas, thus eating into the guard band spectrum in adjacent markets.[4] In addition, TV producers, including TV stations and cable TV operators, have also been granted exclusive use of guard band spectrum for very low-power devices that can be used in production. For example, when a wireless video camera tracks the President's walk to the podium at the opening of his annual State-of-the-Union address, TV guard band spectrum can be used to make the link from the camera to a TV producer.

The FCC's current TV allotment plan mandates that after the DTV transition, channels 52 to 69 will be freed up in all 210 local TV markets in the United States. Four of these channels are being reallocated for public safety agencies, while ten others are likely to be auctioned for exclusive, licensed use by commercial wireless firms. 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. The difference is that these freed up channels will not be contiguous. 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 forty 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 spectrum using 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 guard band channels that would continue to be allotted market-by-market in Swiss cheese fashion after the digital TV transition generated relatively little commercial interest.

However, the technological environment has rapidly changed. With the advent of low-power, "smart radios" providing broadband service, the ability of localized wireless broadband operators to utilize non-contiguous spectrum has dramatically increased. High-tech companies, including Intel and Microsoft, have used their substantial technological and economic credibility to argue that such "smart radios" are the perfect application for this Swiss cheese guard band spectrum. Accordingly, on May 12, 2004, the FCC issued a Notice of Proposed Rulemaking proposing unlicensed use of unused TV channels 2-51 after the digital TV transition, 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. Privately, they have sought to win free access to this guard band spectrum for themselves. Responses to these actions are discussed in depth in two companion papers issued by the New America Foundation.[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.

This paper makes the affirmative economic case for *unlicensed* broadband use of the white space. The basic logic of the argument is as follows. The unused TV spectrum occupies the low frequencies. The best use of low frequency spectrum is for broadband, not broadcast service. *Licensed* spectrum works well for high-power broadband service, but not for low-power broadband service within public or private real property lines. Fundamental forces are driving the world toward wireless networks constituted of low-power devices, such as home WiFi, enterprise WiFi, municipal WiFi and highway WiFi. Therefore, the white space should be allocated to unlicensed, low-power service. In addition, licensed carriers will soon receive more than 150 MHz of additional frequency assignments below 2 GHz (including the ten returned TV channels cleared nationwide), whereas there is a total of only 26 MHz of unlicensed spectrum available at such low frequencies – and it is already heavily used by cordless phones and other unlicensed consumer devices.

The paper is structured in four sections. Section 1 argues that the white space should be reallocated from broadcast to broadband use. Section 2 explains the technological and economic forces behind the shift from licensed to unlicensed use. Section 3 responds to economic objections to this analysis. Section 4 provides an overview of non-economic arguments for unlicensed use.

I. From Broadcast to Broadband

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 popularized the idea of the Negroponte Switch: the idea that video services such as broadcast TV would migrate to wired telecommunications, and audio services such as telephone calls would migrate to wireless telecommunications.[6] In the original formulation of the Negroponte Switch, stationary services (such as broadcast TV) should use wires; and mobile services (such as talking while driving or roaming within your house) should use spectrum. 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 that have made much the same argument.[9] Using different terminology, Sanford C. Bernstein & Co. financial analyst Craig Moffett has recently warned that the TV paradigm is rapidly shifting from "browse" to "search." He explains:

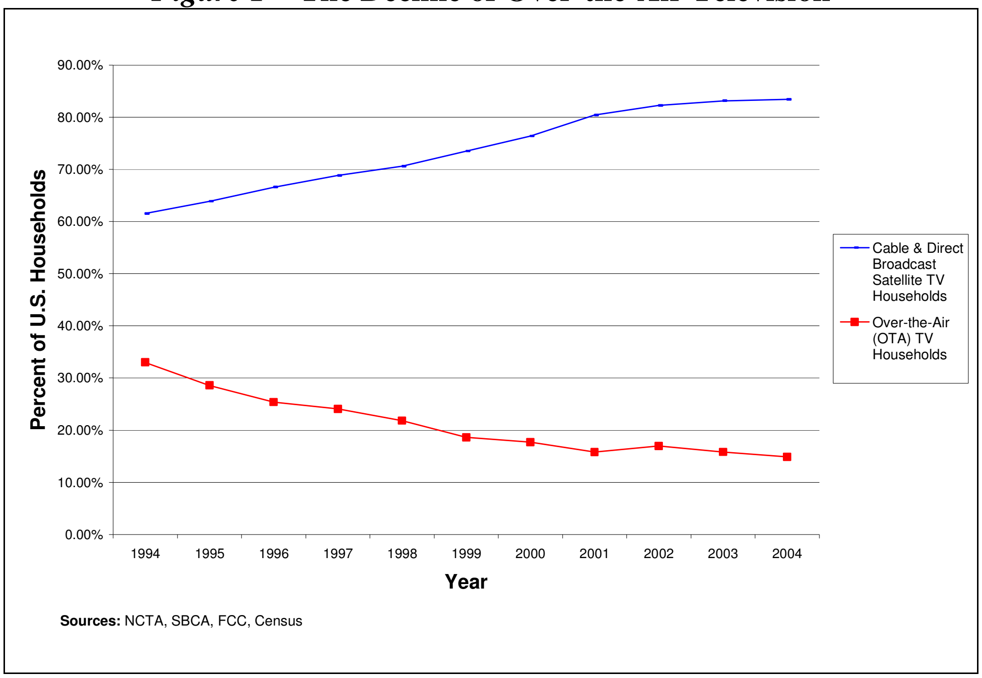
> The transition from browse to search can be characterized… as a shift from "point-to-multipoint" distribution to "point-to-point" distribution. Historically, television has been a broadcast medium; the concept of broadcasting is the very definition of "point-to-multipoint" distribution. But [Video-On-Demand] is different. A VOD stream is a personal, point-to-point communication…. We believe the transition from browse to search is a matter of "when," not "if." And it could come faster than many anticipate.[10]

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. Most notable, 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%,[11] with a drop of about 14 percentage points coming in the last decade alone.[12] This drop is remarkable, given that it has happened 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 TV. So far, the figures for *digital* OTA 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%).[13]

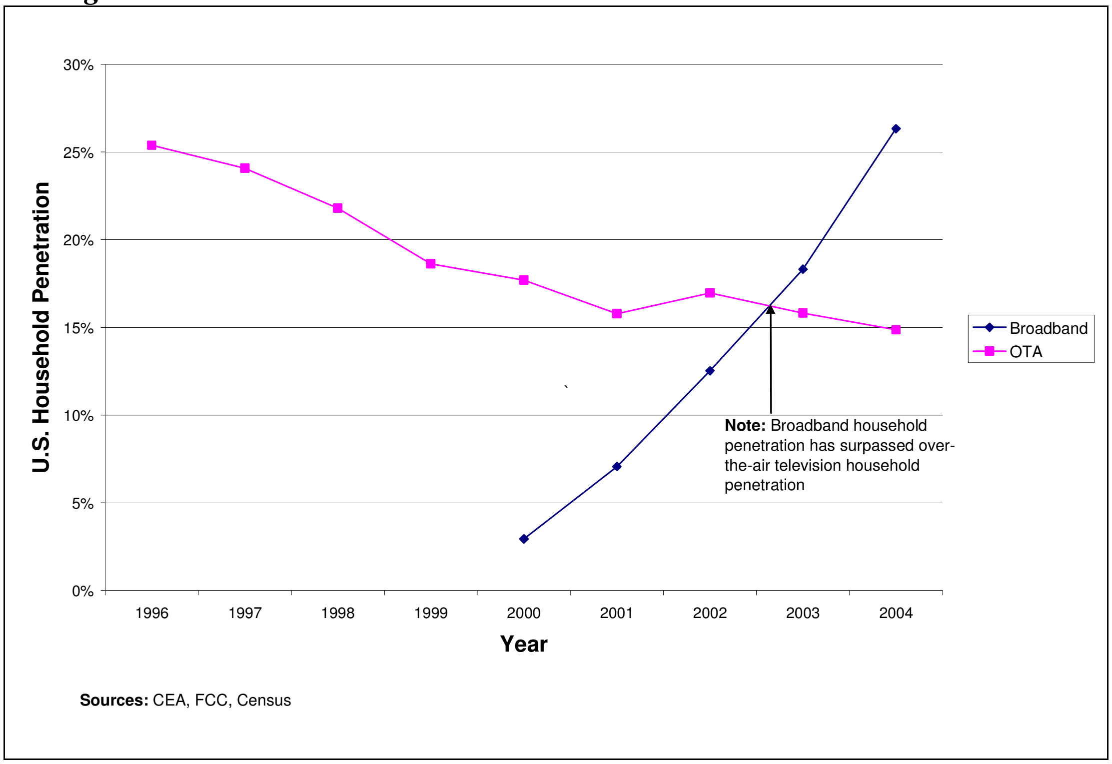
This is not to say that over-the-air broadcasting does not retain a niche, especially among households with low demand for TV or those who cannot get either satellite or cable service for some reason. However, this niche is getting smaller for fundamental technological and economic reasons. Figure 1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



Second, the opportunity cost of continuing to use low frequency spectrum for broadcasting has become increasingly evident. The demand for broadband Internet information 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 nobody purchases 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. Congress has conceded as much in its DTV transition plans for the future of spectrum occupying channels 52-69. No member of Congress is arguing that those channels should be allocated for more conventional digital broadcast TV service. Figure 2 depicts the decline of over-the-air broadcasting and the rise of broadband.

Figure 2 **– The Rise of Broadband and Decline of Over-the-Air Television**



The economics favoring low frequency spectrum for non-broadcast services is based on the physical characteristics of low frequency spectrum. One major physical attribute is that 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.[14] Terrestrial mobile telephone service, for example, is all 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, pets, and other common household obstructions.

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 a point-to-point microwave link used as a backhaul between a building rooftop and a fiber node several miles away linked to the Internet backbone. The primary reason that high frequency spectrum sells for much less than low frequency spectrum is that it competes 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 portable service.

When using a satellite, higher frequency spectrum can be used for mobile applications, such as a truck driving on an interstate highway. But if there is an obstruction overhead (such as a bridge or tunnel) or at the side of the road (such as a steep hill or tall forest), problems may arise. In addition, high-speed, mobile, interactive applications via satellite are not cost effective. The distances covered by a satellite are so great that spatial ("cellular") reuse of spectrum, necessary for ubiquitous high-speed broadband networks, is not feasible. Sending a signal from earth to a satellite also requires more energy than sending the signal to a nearby terrestrial receiver. As a result, battery-powered portable broadband devices that transmit signals to satellite receivers are at a severe competitive disadvantage to those that transmit to nearby terrestrial receivers.

Another major physics-based 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 distance 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 – 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 tower expense 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 or higher towers to reach residents. An Intel study estimates that a rural cell tower transmitting at 700 MHz can cover more than four times the territory of the same tower transmitting at 2.5 GHz.[15] Assuming that towers are the fundamental constraint on rural broadband deployment, low frequency spectrum for broadband can reduce rural broadband deployment costs by a corresponding amount: 75% or more. A similar Spread Spectrum study making the comparison between the TV band versus the 2.4 GHz unlicensed band, found the cost to cover a rural household to be $94 with TV band spectrum versus $677 with 2.4 GHz spectrum.[16]

II. From Licensed to Unlicensed

When household, business, and government entities consider low-power terrestrial 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, tens of millions of American households and more than two-thirds of U.S. businesses use WiFi—a remarkable feat for a product that only became generally available five years ago. Given that the FCC and Congress have strongly favored licensed products in the amount and quality of spectrum they have allocated, this feat is all-the-more remarkable—and an achievement that the legions of Washington lobbyists seeking more spectrum rights for licensed carriers have done everything they can to sweep under the rug.

What explains the shift from licensed to unlicensed spectrum services? Most people would agree it is inefficient for the federal government to sell toll booth rights to third parties to collect payment when anybody uses local real property such as public roads or private homes or businesses. It turns out that the same economic logic is being played out with spectrum rights. Real property may be physical in a way that spectrum is not, but the underlying economic logic is surprisingly similar—and becoming more so. As I will argue, 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 (a federal government mandate that acts, in effect, like a hidden tax) needlessly adds cost while also often reducing quality of service.

The Current Variety of Unlicensed Devices

WiFi is an unlicensed broadband technology that currently offers speeds up to 108 mbps. See Figure 3 for a timeline of WiFi innovations. Other popular unlicensed technologies enjoying explosive growth include Bluetooth, Zigbee, and UWB (ultra-wideband).

***Figure 3* - WiFi Standards Innovation**[17]

Date	**IEEE Standard**	**New Function**
1999	802.11a/b	Base standard.
2003	802.11g	Faster speeds.
2003	802.11h	Implementation of Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC) in the 5 GHz band to avoid military radar.
2004	802.11i	Enhanced security.
2004	802.11j	Additional bands for WiFi in Japan.
2005	802.11e	Quality of service enhancements (e.g., for VOIP and video streaming).
2006	802.11n	Higher speeds and less energy/battery usage.
2006	802.11r	Automated handoffs to facilitate roaming among WiFi nodes.
2007	802.11s	Self-configuring mesh networks.

Unlicensed devices are generally found in four types of locations: homes, work places (including offices, hospitals, 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 6, below, suggests, a growing variety of private and public sector institutions are deploying wide area wireless broadband networks on unlicensed frequencies.

Another way to categorize unlicensed devices is by whether they are linked to devices internal or external to the premise. External links may include access to low bandwidth services (e.g., to plain old telephone service via a cordless phone or dialup Internet service via a remote controlled alarm system) or high bandwidth services (e.g., to cable modem, DSL, or fiber Internet service via WiFi). Internal links may include remote controls (e.g., for garage doors, toys, and car doors), monitoring (e.g., video surveillance, motion detectors, and medical alerts), and machine to machine interactions (e.g., wireless cables for consumer electronics, automated communication between local sensors and appliances, and automated inventory management). The distinction between internal and external is often ambiguous. Consider a warehouse with 10,000 unlicensed radio frequency identification (RFID) tags. As an item leaves the warehouse, the information on the tag is read locally. But it may then be passed on to a distant corporate database.

Another way to categorize unlicensed devices is by whether the communications is automated (machine to machine) or manual (with at least one linked device controlled by a human being in real time). Manual links include cordless phones, VOIP phones, computer laptops, PDAs, and video game players. Automated links include lighting controls, automatic meter reading, wireless smoke and carbon monoxide detectors, HVAC control, heating control, home security, environmental controls, blind-drapery-shade controls, and medical monitoring.

Yet another way to categorize unlicensed devices is whether they have close licensed substitutes currently available in the marketplace. Examples of devices with close substitutes are cordless phones, VOIP WiFi, and PDA WiFi. The vast majority of unlicensed devices have no close licensed substitutes. Mass market examples include garage door openers, remote controlled toys, keyless car doors, invisible dog fences, and RFID tags.

Low vs. High-power Unlicensed Devices

Most important from a policy perspective, unlicensed devices can be either 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.

Small area devices can be networked together to cover a large area, usually still focused within the property lines of a particular entity. Thus, there are two types of unlicensed large area networks: one type comprised of high-powered devices and the other type constituted of many low-power devices. Failure to recognize this distinction between the two types of large area networks has been the source of great confusion or 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.[18] 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 cover the entire 135 square mile-footprint of the city.[19] And the Canamex highway WiFi network in Arizona may cover more than 500 miles before it is complete.[20] Like the blood system feeding hundreds of billions of cells, meshed WiFi networks utilizing public rights-of-way are inherently pervasive. But the individual WiFi nodes of the network, placed on light posts, utility poles, and other roadside structures, cover minimal space.

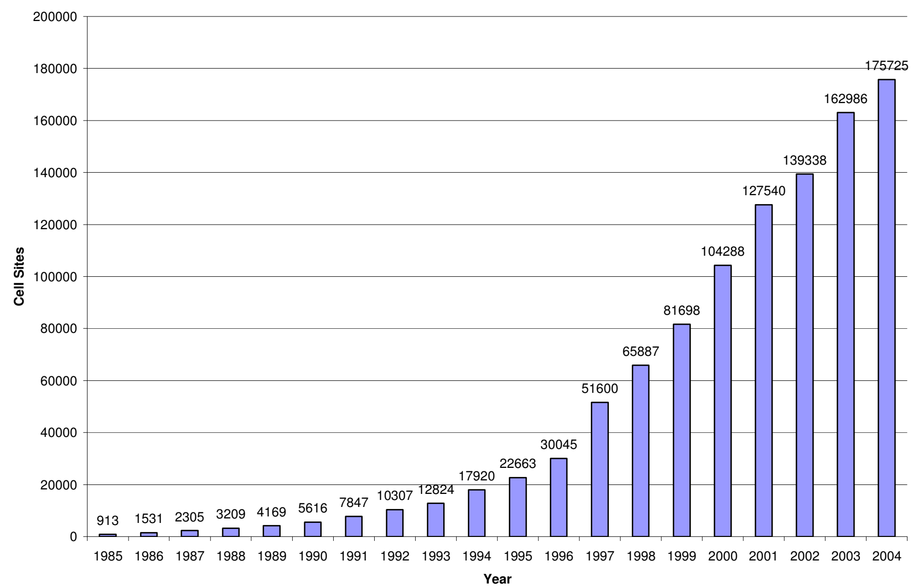
Tens of thousands of other large spaces, including college campuses, hospitals, malls, warehouses, stadiums, K12 schools, amusement parks, and office buildings, have been building networks of small area devices that collectively cover large areas. Similarly, thousands of Wireless Internet Service Providers (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.

A basic rule of thumb in spectrum allocation is that unlicensed spectrum is more efficient for small area devices (including networks of small area devices that collectively cover large areas) and licensed spectrum for 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 self-serving bogeyman related to interference claims, enforcement problems, and tragedies of the commons. 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.

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. 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. 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, largely driven by the need to subdivide cells to increase information capacity.

***Figure 4* - Growth in Cell Sites**



Source: CTIA (all figures as of December)

One major economic force leading to the growth in terrestrial low-power wireless communications is that high-power wireless service has close wired substitutes. 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 bringing high speed fiber lines to the neighborhood and eventually to the premises in every high density area in the United States.

Nevertheless, wireless communication remains a highly valued complement to wired communication. As wired communication nears the individual, it loses its quality advantage because it cannot provide anytime, anywhere service. Note that the value of mobility per se is independent of the distance a wireless signal travels. A wireless network can provide the same degree of mobility whether its nodes are separated by 100 miles or 100 feet.

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.

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 individual, but leave the last part of the communications link wireless.

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. 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. 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.[21] One way to subdivide geographic coverage is with directional antennas that point signals in a specific direction and thus can reuse spectrum in different directions. Another way is to subdivide cells to cover smaller and smaller areas, with each cell able to reuse the same spectrum.

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. A representative in the Verizon Wireless sales department said on October 10, 2005 that its promised EV-DO speeds are currently 300 to 500 kbps. 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—e.g., migrating to digital video, high definition video, glossy magazine quality video (dozens of times higher resolution than high definition video), and even 3D video (requiring at least two separate video streams)—the demand for spectrum bandwidth will continue to skyrocket, requiring ever shrinking geographic coverage. In April 2005, Hong Kong Broadband Network (HKBN) launched a 1 Gbps (1000 Mbps) service for the residential market.[22] In Germany, a country a third the population of the U.S., 2.9 million households are expected to have 50 Mbps by mid-2006.[23]

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 infinite. 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 and a theoretical capacity hundreds of times that. Using today's conventional state-of-the-art mobile telephone cell architecture, there isn't enough low frequency spectrum in the universe 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.[24] Low-power also opens up the possibility of solar powered WiFi, which is useful for a host of military, disaster relief, scientific, developing country, highly rural, and municipal applications where there is unreliable or no electricity.[25]

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.[26] As *IEEE Spectrum* put it, "[C]ellular coverage is usually weakest where WiFi excels—inside homes, stores, and offices."[27] J.D. Power calculates that 3 out of 100 cell phone calls has a quality of service problem.[28] But it doesn't calculate the much greater number of calls that aren't made because people have learned not to expect service. Opening up the TV bands for high-power mobile telephone use will partially alleviate this problem but only low-power devices can completely eliminate it, which is why mobile telephone networks operating on frequencies as low as 800 MHz still install repeaters in high value buildings.

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. The federally planned Intelligent Transportation System also tends to heavily rely on low-power devices.

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.

Perhaps the most surprising advantage of low-power is lower bird mortality. Higher power cell sites require tall towers that kill, for unknown reasons, as many as 4 to 5 million neotropical birds each year. The FCC proceeding on this issue has attracted more interest by environmental groups than any proceeding in its history. Light posts and utility poles have no track record of such bird killings.[29]

All this analysis does not deny the fact that there are economic advantages to large cell sites, most notably the higher 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 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 venture capitalists, entrepreneurs, and manufacturers on the supply side. Now let's look more closely at the economic advantages of unlicensed spectrum.

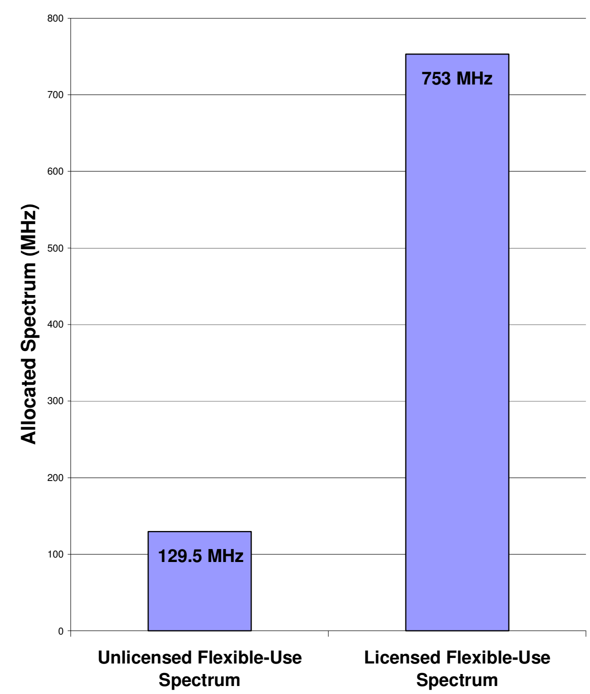
Lower Barriers to Entry for Manufacturers. For manufacturers of wireless products, unlicensed spectrum has lower barriers to entry, leading to more competition and innovation. With licensed technology such as mobile telephone service or public safety communications, entrepreneurs must first get permission from the 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 similar 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.[30] 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. Ibiquity, the new digital radio standard for the AM and FM bands, is a good example. 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.

Figure 5 – Licensed vs. Unlicensed Flexible Spectrum Under 3 GHz



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

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. Note that if an entrepreneur has defensible patents, this delay may not be critical. But there are many business innovations and insights that aren't patentable, where this economic logic would come into play.

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 5).[31]

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 probably 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, most of these companies the public has never heard of 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, or military) can throw into a building and on a remote screen monitor receive 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.

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;[32] 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);[33] and more than 20,000 coffee shops, airports, truck stops, and many other retail businesses in America.[34] Indeed, if being a "carrier" means transporting signals on your own property, then there are tens of millions of unlicensed carriers in the United States alone**.** See Figure 6 below for a sampling of those 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 an entity 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? This 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.[35] The savings for globetrotting executives can be even greater. Instead of paying $1 or more per minute to use an overseas mobile telephone network, they can make a call for free when in reach of a WiFi hotspot in their hotel or corporate office. 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

Figure 6 - Sampling of Wide Area Unlicensed Networks

Universities
University of Akron, Akron, OH
Dartmouth College, Hanover, NH
Carnegie Mellon University, Pittsburgh, PA
Bridgewater State College, Bridgewater, MA
Case Western Reserve University, Cleveland, OH
Trinity University, San Antonio, TX
California State University, Monterey Bay, Seaside, CA
United States Military Academy, West Point, NY
Purdue University, West Lafayette, IN
United States Air Force Academy

Hotels (all with Free WiFi)
Best Western
Candlewood Suites (Intercontinental Hotels Group)
Carlson Hotels Worldwide
Choice Hotels
Courtyard (Marriott International Inc.)
Doubletree Hotels (Hilton Hotels)
Hotel Indiga (Interncontinental Hotels Group)
Howard Johnson (Cendant Corp.)
Radisson Hotels & Resorts

Hospitals
Baycrest Centre for Geriatric Care, Toronto, Canada
Children's Memorial Hospital, Chicago, Illinois
John C. Lincoln Hospital, Phoenix, Arizona
Riverside Methodist Hospital, Columbus, Ohio
St. Agnes Healthcare, Baltimore, Maryland
Sutter Roseville Medical Center, California
Toronto General Hospital, Toronto, Canada
University of Miami Medical Center, Miami, Florida
WakeMed, Raleigh, North Carolina

Manufacturing, Distribution, and Inventory Management
Pacific Sunwear Distribution Center, Orange County, California
Biggs’ Hypermarket, Mason and Harrison, Ohio
Nine Mile Point Nuclear Station
Nike, Memphis, Tennessee
Bridgestone/Firestone, Aiken, South Carolina
Giant Food Stores (98 stores in Pennsylvania, Maryland, Virginia, and West Virginia)
Commercial Alcohols, Brampton, Ontario, Canada

K12 Schools
Lincoln Unified School District, Stockton, California
Sweetwater Union High School, Chula Vista, California
Arlington Independent School District, Arlington, Texas
Covington Elementary School, Fort Wayne, Indiana
Spring Independent School District, 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 locationsBorders Bookstores, hundreds of locations
FedEx Kinkos, hundreds of locations
Flying J truck stops, hundreds of locations
Hertz, dozens of locationsMcDonalds, hundreds of locations
Starbucks, hundreds of locations
UPS Stores, hundreds of locations
Rockefeller Center Concourse, Manhattan, New York
Time Warner Center, Manhattan, New York

Municipalities, Outdoor Public Access
Philadelphia, Pennsylvania (planned)
San Francisco, California (planned)
Corpus Christi, Texas
Daytona Beach, Florida
Marietta, Ohio
Fire Island, New York
Denver, Colorado
Cleveland, Ohio

Municipal, Outdoor Public Safety
Renton Police Department, Renton, Washington
Lower Valley Public Safety Network, Yakima County, Washington
City of Aurora Police and Fire Departments, Aurora, Colorado
City of Everett Police Department, Everett, Washington
Upper Merion Police Department, Upper Merion, Pennsylvania
Village of Buffalo Grove Police Department, Buffalo Grove, Illinois
Baltimore Police Department, Baltimore, Maryland

Convention and Sports Centers
American Airlines Center, Dallas, Texas
Austin Convention Center, Austin, Texas
Connecticut Convention Center, Hartford, Connecticut
Gaylord Texan Resort and Convention Center, Grapevine, Texas
LA Mart, Los Angeles, California
Miami Beach Convention Center, Miami, Florida
Monterey Conference Center, Monterey, California
New York Gift Mart, New York, New York
Greater Fort Lauderdale Broward County Convention Center, Fort Lauderdale, Florida
William A. Egan Civic and Convention Center, Anchorage, Alaska

Airlines (only international travel)
Austrian Airlines
Lufthansa
SAS
El Al
All Nippon Airways
Asiana Airways
China Airlines
Japan Airlines
Korean Air
Singapore Airlines

Airports
Atlanta International Airport, Atlanta, Georgia
Baltimore-Washington International Airport
Boston, Logan International Airport, Boston, Massachusetts
Detroit Metropolitan Wayne County Airport, Detroit, Michigan
LaGuardia International Airport, Flushing, New York
Los Angeles International Airport, Los Angeles, California
Louisville International Airport, Louisville, Kentucky
McCarran International Airport, Las Vegas, Nevada
San Diego International Airport, San Diego, California
Ted Stevens Anchorage International Airport, Anchorage, Alaska

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

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 DTV and public safety equipment with WiFi equipment. WiFi radios are of at least comparable and arguably far greater sophistication than the typical DTV or public safety radio. For example, a $30 WiFi access point available at Best Buy can both send and receive data; cover multiple unlicensed bands from 2 GHz to 5 GHz; span more than 500 MHz; simultaneously process multiple channels, each with a capacity of at least 54 mbps; send and receive multiple sophisticated control channels to facilitate spectrum sharing; and include extensive spectrum sharing intelligence. A stand alone DTV receiver, in contrast, costs about $200 at Best Buy (even now that the FCC-mandated deadlines for equipping most new televisions with DTV receivers have begun to kick in – which should, theoretically, result in a drop in the price of such receivers due to economies of scale in production); can only receive data; covers several bands all below 1 GHz; spans 402 MHz; can simultaneously process only 1 channel, each with a capacity of only 19.4 mbps; sends no specialized signals to coordinate efficient spectrum sharing; and need incorporate no intelligence to share spectrum, even spectrum that lies completely fallow.[36] Indeed, the intellectual property royalty fee on a DTV chip, approximately $11.50, is greater than the approximately $5 total cost of a WiFi chip in bulk purchases by OEMs (original equipment manufacturers). With public safety equipment, the economics tend to be even worse. 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.

The most dramatic economies of scale are likely to occur with unlicensed radio frequency identification tags, which are already beginning to replace the ubiquitous bar codes on shipping manifests and retail products. The unlicensed chips are expected to soon be manufactured at the rate of hundreds of billions per year. Whereas they already cost less than $1/chip, it is widely expected that by 2010 they will drop to below 5 cents/chip.

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. Alternatively, an entity may standardize on one mobile telephone carrier. But this may dramatically increase switching costs, something of great concern to most businesses.

A similar logic may apply to installing wireless networks on public rights of way. For example, it may be less expensive to install a single WiFi network in an underground metro system than a half dozen proprietary networks from competing mobile telephone vendors. Of course, a metro system could choose to maximize its revenue by asking the competing mobile telephone operators to bid on winning an exclusive metro contract. But in this case the winning bidder(s) will be able to charge users monopoly prices for wireless communication. If wireless metro broadband is a public utility rather than a source of revenue to subsidize other government activities, then charging a monopoly price won't optimize consumer welfare.

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. Here I want to emphasize why the most demanding wireless users, notably large, sophisticated businesses, are shifting to unlicensed use for reasons not of cost but of quality.

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 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. In certain businesses such as hospitals, hotels, warehouses, retail stores, and universities, a large fraction of employees are constantly moving around. And in almost every business, there are at least some employees who spend a large fraction of their day on premise but away from their desks. Indeed, in the vast majority of businesses, the number of mobile on-premise employees dwarves the number of off-premise mobile employees. Businesses want these on-premise mobile employees to use portable rather than fixed phones and computers, and they want these portable devices to be able to be reachable via the same internal extension wherever they are.

Businesses also want internal control of 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. Writes Donny Jackson in *Mobile Radio Technology*:

> Coverage always has been an issue in the wireless world, especially inside buildings. Otherwise strong wireless signals often don't penetrate building walls well and sometimes are stopped altogether. The problem is particularly severe in larger buildings that typically serve more wireless users - not only do these buildings feature sturdier materials that block radio signals, the large number of people they serve during peak periods can create capacity issues for any in-building coverage system that is deployed. As a result, in-building coverage is a sore subject for many wireless service providers. "The fact is, sometimes [in-building coverage strategies] work, and sometimes they don't," said a spokesman for one prominent wireless carrier. "We don't care to talk about it."[37]

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.

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.

At least for now, there is also a much greater choice of content via unlicensed spectrum because licensed mobile telephone carriers have typically refused to offer content unless they receive a cut of the revenues. The content providers that offer the carriers the greatest profits get privileged broadband access. To date, the wired backbone providers for unlicensed networks have not restricted content in this way.

III. Economic Arguments Against Unlicensed Spectrum

The main economic argument against unlicensed spectrum is that it would create a "tragedy of the commons."[38] By this is meant that unlicensed spectrum would result in chaos due to lack of well defined property rights and excessive spectrum use. The counter argument is that just as many resources, including free speech, public highways and seaways are best managed as a commons, so is spectrum. My point here is not to argue whether or not spectrum is best managed as a common resource, but to say that this argument is irrelevant to the argument I have presented.

More than 99% of unlicensed devices are primarily used within public or private property boundaries, and so it is appropriate to develop an economic argument for or against unlicensed spectrum that is based on that practical fact. Under current FCC rules, unlicensed devices operate at such low power that the property owner can in most cases prevent an over-population of devices operating on the same frequency. And even where competing uses conflict, the benefits of free and unfettered access to the airwaves far outweighs the occasional cost or inconvenience of repositioning or replacing a device. That is why the FCC currently accepts the fact that the 350 million cordless phones, baby monitors, microwave ovens and home WiFi networks may sometimes temporarily interfere with one another. Indeed, careful reflection reveals that there are very few economic activities in the world without some type of externalities. When my children play in the back yard, for example, my neighbors on the sides and behind my house can hear their chatter.

One commonly alleged tragedy of the commons is the use of unlicensed spectrum by WISPs, which provide broadband Internet service in rural areas via unlicensed spectrum. But here again, some common sense needs to prevail. WISPs cannot send unlicensed signals with any more power (1 watt) than homeowners or businesses using WiFi within their premises (in contrast, many TV stations transmit at over 1 million watts). But they focus the energy in a particular direction and may install more sensitive receivers so fainter signals can be picked up. The result is that the signals may pass over many miles. But since WISPs are predominantly in rural areas, they are passing for the most part over open land. Even if the signal directly passes over a handful of houses, that's a comparable effect on neighbors to my kids shouting in my backyard or my WiFi signal being detectable to all my 1st adjacent or 2nd adjacent neighbors.

The real economic tragedy, is the huge amount of spectrum that high-power licensed users waste. Local TV broadcasters, for example, have historically "polluted" approximately 9 square feet of spectrum for every square foot they used. This is because the channel spacing needed to accommodate "dumb" analog over-the-air TV sets resulted in huge amounts of unused guard space—the very space that advanced digital technology now makes usable. In addition, broadcasters claim that their technology is so primitive that it cannot exist with spectrum underlays, also known as whispering rights. This means that even if a household or business isn't tuned in to any of the 67 over-the-air TV channels on its premises, it must refrain from using that spectrum to send a low-power signal within its premises that wouldn't have a material impact on receivers outside its premises.

Four additional economic arguments are independent of the anti-commons argument. The first is the market expenditures argument. According to this argument, expenditures on spectrum equipment and services are a valid proxy for economic productivity. Economist Thomas Hazlett, for example, has argued that more licensed spectrum for flexible use services such as mobile telephone service is much more valuable than for unlicensed service because of the differing amounts spent on consumer services (e.g., monthly minutes used), consumer equipment (e.g., cell phones), and network equipment (e.g., cellular towers).[39] See Table 1.

***Table 1* - Market Expenditures on Licensed vs. Unlicensed Equipment & Services**

Type of Service	Service Revenue	Equipment Revenue	Capital Equipment Expenditures	Total $ / Total %
109.5 MHz allocated to unlicensed at 900 MHz and 2.4 GHz	$0.09 billion	$3.81 billion	$0.26 billion	$4.16 billion / 3.2%
189 MHz allocated to licensed at 800 MHz and 1.9 GHz	$88 billion	$13 billion	$21 billion	$132 billion / 96.8%

The implication of this data is that licensed spectrum is about 30 times as productive as unlicensed spectrum. Although this type of analysis is quite common, I haven't seen an economist or interest group make this argument in anything more than an anecdotal way to buttress an anti-commons argument. I believe that's largely because they know that its surface appeal for unsophisticated audiences won't stand up under close scrutiny. Hazlett himself acknowledges: "Annual equipment expenditure data [for unlicensed] cannot be directly compared to lump sum present values [for licensed]…. Yet, the magnitudes are not close enough to warrant further inspection."[40]

There are many goods for which no or little direct fee is charged but that provide great social welfare. Examples include the air we breath, the water we drink, and the sunset we view in the evening. Just because a product is relatively inexpensive does not mean it doesn't greatly contribute to social welfare. To pick a textbook economic case, what is more valuable: a diamond or a glass of water? The price of a diamond is generally far greater than a glass of water. But if one had to choose between a diamond and dying of thirst, the glass of water would be more valuable because water is essential for life but diamonds are not. So should we conclude that because diamonds currently sell for more than water that diamonds create more consumer surplus than water? Obviously not.

Similarly, just because consumers don't pay for WiFi service and the cost of equipment to access it is negligible--thanks to robust competition and huge economies of scale--doesn't mean that the consumer surplus associated with unlicensed devices is not huge. Consider a consumer's cost saving from installing a WiFi network in his home rather than rewiring the home. The savings can be many thousands of dollars, but Hazlett ignores this type of economic benefit in his analysis. A monopolist with exclusive control of the spectrum in a consumer's home could presumably force the consumer to pay a fee closer to the value of the wired substitute. And to collect this fee, he might invest in expensive equipment to create a toll booth in the consumer's home. But would this be better for society? Clearly not. But according to Hazlett's casual analysis, this demonstrated consumer willingness to pay would demonstrate greater social value.

A second argument is that it doesn't matter what are the relative economic benefits of licensed versus unlicensed spectrum because only the market can determine those benefits for licensed spectrum and the government's track record of making those calculations—whether for unlicensed spectrum or any other good—is abysmal. Hazlett argues, for example, that "[a] caveat is that there is no entirely reliable way to compare two distinct possible uses for spectrum. This, in fact, forms the argument for market allocation of spectrum."[41] But, as we have seen, licensed and unlicensed spectrum are both forms of private property. The only significant difference is that in the case of unlicensed spectrum the original real property owner retains the spectrum rights, whereas in the case of licensed spectrum they are taken away by the government—via what may be viewed as a form of eminent domain—and assigned to a license. Indeed, taking away spectrum via eminent domain (and, say, giving it to the TV broadcasters) is likely to be subject to far more government abuse than keeping the spectrum in the hands of its original property owners.

A third argument is that high-power spectrum allocations have greater economies of scale than low-power allocations. It's expensive to run a broadband service and the numerous fixed costs can be better spread over a large customer base. But it is not at all clear why this is necessarily so. For example, why would it be truer for on-premise wireless networks than on-premise wired networks, which are almost always locally controlled? The same logic applies to wireless equipment. For example, most people would laugh at anyone who suggested hiring Verizon, Cingular, or some other licensed spectrum holder to install a cordless phone purchased at Best Buy or Circuit City. To the extent there are economies of scale, a municipality or business or household can hire a third party. This may or may not be a licensed spectrum holder, for there is nothing about being a licensed spectrum holder that makes one inherently more efficient at installing equipment. Moreover, for small networks, there may be diseconomies of scale associated with licensed spectrum because of the need to install different equipment from different license holders that essentially perform the same service.

A fourth argument is that low-power spectrum allocations will result in higher transaction costs for consumers and carriers. One key assumption behind this argument is that low-power spectrum rights are worthless because only high-power rights can transmit across desired distances. As a result, many low-power rights holders would have to sell to high-power users or engage in costly coordination activities in order for the spectrum to realize its value. These extra transactions result in needless costs, so the FCC should simply start by allocating wide area licenses. The basic problem with this argument is that it ignores the possibility that low-power devices may offer significant quality improvement over high-power spectrum while being cost effectively connected into a large area network, such as hundreds of municipalities are doing with their WiFi networks.

Another key assumption is that transaction expenditures associated with roaming across a wide area would be excessive. But this needn't be the case. Companies such as Boingo, Wayport, and T-Mobile have already linked tens of thousands of public hotspots in seamless networks. And Pronto has begun to link municipal networks into a mega network. Moreover, in the long-term, charging for packets of information sent in a low-power wireless architecture may turn out to be as inefficient as it is today to charge for packets sent over the wired Internet. It may simply be easier to offer the service free to employees and customers. No less a capitalist than New Corp. CEO Rupert Murdoch has predicted that "free voice is going to be ubiquitous" and "not in 10 years; within two or three years."[42] Similarly, municipalities and transportation departments don't charge a separate fee every time a driver sees by the light of a roadside light post, gathers information from a roadside sign, or makes a turn in the road; it's not at all clear why they should charge for a roadside WiFi network that also has essentially zero marginal cost. The cost of such networks, like other road amenities, may be most efficiently built into toll taxes, gas taxes, and general taxes. Perhaps, then, the economics of the mobile and wired Internet will converge, with both types of networks setting up peering agreements between providers that allow information packets to be sent over multiple vendors at zero marginal cost to consumers.

Even equipment transaction costs are rapidly becoming negligible. Emerging software defined radios should be able to roam from network to network, regardless of frequency and standard, because that is what software defined radios are designed to do. With standardized WiFi phones, much of this flexibility already exists. Indeed, it is licensed services that appear to artificially inflate the cost of switching equipment and networks. Most licensed mobile phone providers, for example, insist that mobile phones used in their bands cannot be used with a competing provider. The basic phone is usually manufactured to work on the networks of at least several of these competing providers. But this ability is disabled by insisting that a special chip be added to the phone. That way the consumer is forced to bear the burden of purchasing a new phone when switching providers. By making transaction costs as high as possible, competition is thus restricted.

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 medium for speech. 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.[44] Every European and North American country allows unlicensed WiFi.

Universal Service. America is now 13th in the world in broadband penetration.[45] Low frequency, unlicensed spectrum is critical to bringing affordable broadband services to poor, undeserved 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, is offering broadband service to low income households for $10/month, less than 25% 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. 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 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 takings of their property without just compensation. Note that just as property owners have no rights to airspace 500 feet or more above their homes, many spectrum rights, such as satellite-to-satellite and satellite-to-earth, are not local and thus would not fall into this scheme.

Of course, "property rights" to electromagnetic spectrum must be tempered by free speech rights just as they are with acoustic spectrum. 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.

Property rights also need to be tempered by anti-monopoly considerations. If a private or public entity has undue monopoly power, its powers should be limited, as is now done via the anti-trust laws at the U.S. Department of Justice and the Federal Trade Commission. The closest parallel at the FCC concerning spectrum management may be the over-the-air reception devices (OTARD) rules, which prevent a landlord from extracting a monopoly rent from a tenant for installing a relatively inconspicuous antenna to pick up a signal. Another parallel at a local level may be municipalities' insistence that their municipal WiFi networks be open to all content providers on equal terms. Much of this open access should be a simple matter of common sense and marketplace norms. For example, just as people can freely chat at a private mall, they will probably be allowed to use their unlicensed car door opener in its parking lot.

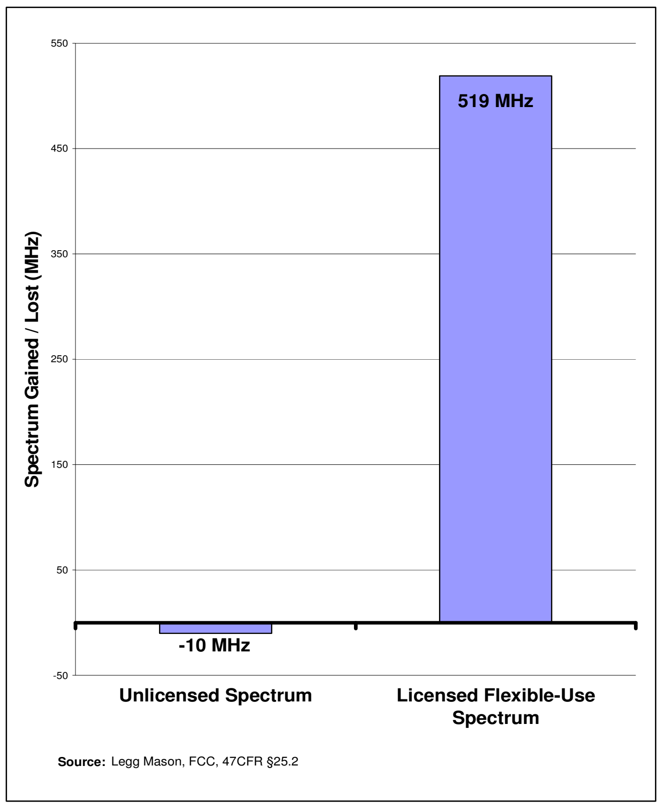
Conclusion

The opposition of licensed spectrum holders and their vendors to unlicensed spectrum is nothing new. Indeed, in one of the greatest fortuitous turns of telecom history, the only reason there is any substantial unlicensed use below 3 GHz is that the bands allocated to unlicensed were considered junk bands unsuitable for anything else. The so-called unlicensed bands were originally called the Industrial, Scientific, and Medical (ISM) bands. Any device, such as a consumer microwave oven or industrial heater, that used radio frequency energy for any purpose other than for telecommunications was required to emit its energy within these bands. Unlicensed devices were allowed to operate in these bands as long as they operated at very low-power and accepted interference from these other products. In addition, they had to accept interference from higher power amateur radio and military users in the ISM bands. Despite these limitations, unlicensed services have thrived in these bands.

Unfortunately, however, there are no more low frequency "junk" ISM bands that Congress and the FCC can allocate to unlicensed. The TV guard bands are the last remaining low frequency bands that Congress and the FCC can allocate to unlicensed without terminating or buying back the license of an incumbent spectrum holder.

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 growth of home WiFi, enterprise WiFi, and municipal WiFi.

Figure 7 - Reallocations of Spectrum Below 3 GHz Since November 2002 Spectrum Policy Task Force Report



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. This means that both more spectrum needs to be made available for unlicensed use and license terms should be made as short as possible so that future adjustments can be made in light of the growing need for unlicensed spectrum. In fact, federal 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.[46]

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 political disgraces and 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*, July 23, 1990.
[4] J.H. Snider, *Speak Softly and Carry a Big Stick: How Local TV Broadcasters Exert Political Power* (New York: iUniverse, 2005), Appendix D: Valuation of Guard Band Spectrum Acquired by Broadcasters (1997-2004).
[5] For a discussion of the broadcasters' technical arguments, *see* Michael J. Marcus, Paul Kolozy and Andrew Lippman, "Reclaiming the Vast Wasteland: 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.

[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., *see* 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*.

[10] Craig Moffett, "Cable and Satellite: Search Versus Browse," in *Bernstein Research Call* (New York City: Sanford C. Bernstein & Co., 14 July 2005). See also William Cooper and Graham Lovelace, "IPTV: Broadband meets Broadcast—The Network Television Revolution," (London: InformIT, September 2005), available at ip-report.com.

[11] *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.

[12] *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.

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

[14] *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.

[15] Masud Kibria and Chris Knudsen, "Capital Expenditure Implications of Spectrum Assets in Semi-Rural Environments," (Hillsboro, Oregon: Intel, 4 August 2005).

[16] Mark McHenry, "Solving the Broadband Access Problem Using Dynamic Spectrum Sharing Technology," (Vienna, Virginia: Shared Spectrum Company, October 2005).

[17] The FCC authorized WiFi type spread spectrum unlicensed devices in 1985 in Docket 81-413.

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

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

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

[21] *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.

[22] Georgina Lee, "Earful," South China Morning Post, October 4, 2005, p. 4.

[23] "Deutsche Telekom: 50 Mbit/s Broadband Announced," Digital Lifestyles, 1 September 2005.

[24] *Supra* Note 12.

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

[26] 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.

[27] "A Match Made in Packets--Coming soon: cellular handsets that can use a WiFi network," *IEEE Spectrum*, July 2005, p. 14.

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

[29] FCC Notice of Inquiry in the Matter of Effects of Communications Towers on Migratory Birds," WT Docket 03-187. See also D.A. Keckler, "Avian Mortality," *Above Ground Level*, August/September 2005.

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

[31] 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).

[32] 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.

[33] 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.

[34] "2005 Telecommunications Market Review and Forecast" (Arlington, Virginia: Telecommunications Industry Association, 2005), p. 165.

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

[36] For example, households and businesses that receive their broadcast TV via cable or satellite--or that don't want broadcast TV at all--could theoretically allow low power devices within their premises to use the entire TV band without interfering with any other entity's broadcast TV reception. The same basic logic applies to the small minority of households that rely on over-the-air TV. They typically only tune into one or at most a few channels at a time, theoretically allowing them to make local, low power use of the dozens of other channels. But all this assumes a rudimentary level of intelligence—the type of intelligence embedded in a $5 WiFi chip.

[37] Donny Jackson, "Dual-Mode Phones Key to Coverage," *Mobile Radio Technology*, 1 July 2005.

[38] See Hazlett, "Spectrum Tragedies." For counter arguments within the commons paradigm, see Mark Cooper, "The Economics of Collaborative Production in the Spectrum Commons" (Stanford, California: Center for Internet & Society, Stanford Law School, 2005), William Lehr, "The Economic Case for Dedicated Unlicensed Spectrum Below 3 GHz" (Washington, DC: New America Foundation, July 2004), and William Lehr and John Snowcroft, "Managing Shared Access to a Spectrum Commons," Unpublished Manuscript, September 2005.

[39] Thomas W. Hazlett, "Spectrum Tragedies," *Yale Journal of Regulation* 22, no. 2 (2005): 260. See also Thomas W. Hazlett, "Ownership, Innovation, & Qualcomm," presented at Qualcomm's 20th Anniversary Event, held at the United States Chamber of Commerce, Washington, D.C., 26 July 2005, and FCC Comments of Thomas W. Hazlett and Matthew Spitzer in the Matter of *Establishment of an Interference Temperature to Quantify and Manage Interference and to Expland Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands*, ET Docket No. 03-237, 5 April 2004.

[40] Ibid., p. 30.

[41] Ibid., p. 28.

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

[43] Stacey Higginbotham, "'Always on' Wireless: Like Flicking a Switch, *News.com*, 9 September 2005.

[44] 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.

[45] S. Derek Turner, "Broadband Reality Check: The FCC Ignores America's Digital Divide," (Washington, DC: Free Press, August 2005).

[46] 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).