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Breaking the Chains: UNLICENSED SPECTRUM AS A LAST-MILE BROADBAND SOLUTION

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Man is born free; and everywhere he is in chains. – Jean Jacques Rousseau

Rousseau might just as well have been talking about telecommunications. Most people still can't imagine computer networking without cables. Before Wi-Fi, people who wanted ubiquitous broadband access had to snake wires through their homes or offices. It was a very expensive and often impractical proposition. And even then, the broadband user was chained to a wire. Wi-Fi meant freedom. By creating a wireless local area network (WLAN), a Wi-Fi device can go anywhere; equipment is inexpensive; access to the airwaves is free within one's own home; and communication is very fast, or at least it would be if not limited by the sluggish wirelines that connect most WLANs to the backbone. But Wi-Fi only breaks the chains on the last hundred feet of the telecommunications network. The rest of the last mile is still in chains.

Some of these chains are physical. They are the twisted-pairs of copper wire of the telephone network and the coaxial cables of cable television that connect users (and Wi-Fi access points) to the outside world of the Internet. Others are institutional. They are everybody with a government-granted airwaves license or monopoly over last-mile service. They are the telephone, cable, cell phone and broadcast companies. And they are the Federal Communications Commission – the master enforcer of all government-granted, last-mile telecommunications monopolies.

Is Wi-Fi, and the mobility it provides, just the tip of the iceberg of the unlicensed wireless revolution, or is it the iceberg itself? If it is only the tip, then much or all of the rest of the "last mile" (or last 40 miles) can also be freed from its wired and government-licensed chains. But for that to happen, the government would have to decide to break the chains—chains that are bringing current last-mile vendors tens of billions of dollars in monopoly profits and that are being held in place by a phalanx of telecom lobbyists as powerful in their sphere as the Roman legions were in the heyday of theirs.

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Leading the charge to provide unlicensed service over the last mile are wireless Internet service providers (WISPs). WISPs use unlicensed spectrum to connect small businesses, farms, home-schooling families, and others as far as 35 miles from wireline connections. Currently, tens of thousands of mostly rural Americans receive broadband Internet service via WISPs. WISPs have been especially important to bringing broadband Internet service to rural and low-income areas, where wireline broadband connections are either unavailable or unaffordable. Despite being relegated to relatively high frequency bands (typically the unlicensed bands at 2.4 and 5 GHz), which cannot readily pass through trees and walls the way broadcast television and other low frequency services do, WISPs nevertheless provide high-speed connections at a fraction of the cost of upgrading wireline connections. Like VHF-TV broadcasters, if last-mile providers had access to the "white space" in the grossly underutilized low-frequency bands (below 800 MHz), both WISPs and non-profit community networks could more cost-effectively transmit broadband access from a high building, tower or hilltop over many square kilometres – and through the canopy of trees that surround many residential and commercial areas. Rural and low-income access to fast and more affordable broadband connections would skyrocket.

Unfortunately, the current debate over last-mile broadband policy is all too often a sterile debate over policies related to the wired infrastructure. The debate needs to shift to spectrum policy. Spectrum is not just a third last-mile broadband platform to compete with cable modems and DSL. It is the platform of choice. The wired infrastructure belongs in the backbone, not in the consumers home, lawn, or neighborhood.

For unlicensed wireless service to reach its full potential as part of the last-mile broadband solution, we need fundamental changes in spectrum policy, including: 1) more spectrum allocated to unlicensed service, especially at the lower, more cost-effective frequencies, particularly below 800 MHz, and 2) more low power services such as WISPs that make highly efficient use of spectrum.

The Wired Broadband Infrastructure

When the Internet was first opened to the public in the 1990s, consumers had no choice but to connect via modems over conventional telephone lines. Only the telephone network could provide service over the so-called "last mile" to homes and offices. Federal common carrier regulations allowed any computer to transfer data and to network through the local telephone system, as telephones do. The problem is that telephone dial-up connections are agonizingly slow. In a few years, faster, broadband connections became available. Yet, the wired communications infrastructure remained static, consisting of giant telephone and cable television companies, which are the only ones covering the last mile. Consumer choice is limited, at best, to two service providers. Telephone companies call their broadband connections Digital Subscriber Lines (DSL) while cable companies refer to theirs as cable modem service.

The term "broadband" is commonly used to refer to a high-speed digital connection. The FCC considers a high-speed connection to be 0.2 Megabits per second (Mbps) or faster.

That speed permits a new Web page of mixed text and graphics to appear on a computer monitor in about the same length of time that it takes to turn the page of a book. A dial-up connection operates at less than a quarter of this speed. Critics of the FCC's definition say 0.2 Mbps isn't fast enough to deliver compelling applications and new services to the consumer. For example, transmission of DVD-quality video in real time requires a speed of about 5 Mbps, twenty-five times faster than the FCC's threshold; HDTV requires about 10 Mbps; and the proposed digital cinema standard, up to 200 Mbps.

While a single strand of fiber optic cable carries tens of billions of bits of data per second, residential Internet connections over copper phone and cable wires rarely exceed one million bits per second down-stream (and 256 thousand bits per second upstream). A symptom of the failure of U.S. broadband policy is that the rate of innovation in the telecommunications backbone far exceeds the rate of innovation in the "last mile."

The speed of a telephone company DSL line depends upon how far the home is from the company's facilities—the farther the distance, the slower the speed—and the home must be within about 2 miles of phone company facilities for DSL to work at all. Thus, although most homes in the United States can have wired telephone service, many cannot get a DSL broadband connection. DSL is generally marketed at speeds ranging from 0.384 to 1.5 Mbps. Cable modem service is usually stated as having a speed of 2 Mbps (in practice, this speed is rarely attained on a sustained basis).[1] Both of these figures represent the downstream speeds, the speeds at which information enters the house. Upstream speeds, the speed at which information leaves the house is typically much less—rarely above 0.256 Mbps. The large discrepancy between upstream and downstream speeds means that applications such as VHS videotape quality videoconferencing are not feasible. VHS videotape has about half the resolution of standard broadcast TV and requires upstream speeds well above 0.256 Mbps.

Thus far, cable modem service has proved vastly more popular. FCC statistics show 6.8 million residential and small business customers for cable broadband and only 1.6 million for DSL.[2] Cable has 79% of the last-mile broadband market even though cable lines connect to substantially fewer homes than telephone lines do.[3]

In certain foreign countries, notably Japan and South Korea, broadband penetration rates and speeds are higher than in the U.S., while also charging lower rates. By the end of 2003, more than half of Japanese households are expected to have broadband service at 12 Mbps and at prices about half that of broadband service in the United States—which operates at speeds only a small fraction as fast.[4] As of the end of 2002, South Korea had broadband penetration rates of 57.4% (compared to 22.8% for the U.S.) with speeds up to 40 Mbps.[5] A common explanation for the superior Japanese and South Korean broadband service is that high household density reduces the cost of wiring households for broadband.

Wireless Last-Mile Connections: Licensed vs. Unlicensed

The success of Wi-Fi for local area networks, with connection speeds far exceeding wired broadband,[6] raises the obvious question of whether wireless can serve the last mile to home and office. In rural areas where DSL and cable modem services are typically not available, wireless seems the only economically feasible way to deliver broadband. In urban areas, wireless may be a more affordable alternative to the wired infrastructure of telephone and cable companies.

From a regulatory perspective, there are two fundamentally different approaches to wireless broadband. The first approach is the traditional one that allocates specific bands of spectrum available for a service and implements a program of licensing providers. This is the way cellular phone service is provided today.[7] The second approach follows the spectrum allocation system that made Wi-Fi successful and relies on what is often called "unlicensed spectrum," meaning frequencies where radio transmitters may be used without an FCC license.[8] While licensing gives cell phone companies virtually exclusive use of a band, Wi-Fi users share unlicensed frequencies with no protection against interference.

Most licensed spectrum is licensed for high power services, while license exempt spectrum operates under special rules that require unlicensed devices to operate at low power and hence over short distances. High power licensees, such as broadcasters and cellular carriers, can transmit signals that cover a large geographic area.

There is a general consensus that unlicensed allocations maximize efficient spectrum usage for very low-power applications and that licensed allocations maximize efficient spectrum usage for high-power services. For example, few argue it is efficient (or fair) to charge individual citizens for access to the public airwaves when they are operating their low power TV

Loudoun County Virginia:
Two Start-up WISPS Connecting the Suburban and Rural Last Mile

Despite their proximity to northern Virginia's Internet backbone, many towns in Loudoun County have no broadband access. The mountainous western regions of the county are removed from the technology infrastructure of Northern Virginia where companies like AOL and VeriSign reside. However, because of license-exempt wireless technology, entrepreneurial companies like Roadstar Internet Services and SkyNet Access are bringing the high-speed Internet to these rural and suburban areas.

The residents of Northern Virginia are a diverse mix of professionals who came to the area during the technology boom of the late 90s. When the technology bubble burst, as many as 30,000 jobs in the region were lost. However, because many laid-off professionals started their own businesses or began working from their homes as contractors, demand for high-speed home services remained. SkyNet Access, a Wireless Internet Service Provider (WISP), is trying to meet that demand in the Leesburg suburbs.

"Infrastructure, infrastructure, infrastructure" is the rallying cry for local businesses, says Chris Chamberlain, President & CEO of SkyNet Access. He contends that unlicensed wireless technology helps small businesses compete with larger firms. SkyNet relies on a variety of unlicensed bands (2.4 GHz, 5.2 GHz, 5.7 GHz, and 5.8 GHz) to reach over 100 businesses and residential subscribers in the area.

A local vineyard and a successful home-based e-commerce venture are among SkyNet's subscribers. In the coming months, they plan to extend their network into more rural areas of the county. In doing so, they will compete with another local WISP, Roadstar Internet Services.

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remote controls, garage door openers, microwave ovens or cordless phones, so use of spectrum at low power levels should remain unlicensed. Similarly, few argue that it is practical to allow everyone to be their own licensed high power TV or mobile telephone broadcaster.

Nevertheless, the track record of the high power licensed approach has been mixed. It has worked well with cellular telephone service. In the twenty years since the first cellular license was issued, wireless telephone networks have grown to be viable competitors with the wired infrastructure for the provision of voice services.

The licensed approach has proven less successful, so far, with respect to broadband. Local Multipoint Distribution Service (LMDS)[9] is one example. It was conceived as a service that could deliver wireless broadband to office and apartment buildings. The licensing strategy was to sell two exclusive licenses per market, with each licensee serving as a conventional telecom carrier. It was not strictly a last-mile service because the plan was principally to service high-rise buildings. Signals would be transmitted to an antenna on the roof of a building and carried to offices and apartments within the building over wires. LMDS used frequencies in the 27-31 GHz bands. Transmissions at such high frequencies have a range of between two and five miles, and so honeycombed, cellular configurations with multiple hubs were planned. In 1998, the FCC auctioned off part of the LMDS spectrum and netted the government $579 million.[10] A second auction in 1999 brought in $45 million.[11] LMDS equipment and sales costs remained high and demand low. Many bidders went bankrupt.

Lower frequencies, in the 2-11 GHz range, were also tried for licensed wireless broadband, but these trials failed too.[12]

Loudoun County Virginia:
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Started in the autumn of 2002 by entrepreneur Marty Dougherty, the Roadstar network connects over 100 rural households and small businesses. Their customers include home-schooling families, telecommuters and small businesses who can now use high-speed applications like video conferencing and file sharing. Most importantly, the wireless connection rivals prices paid by DSL and cable subscribers in eastern Loudoun County.

The first leg of the Roadstar network travels 18 miles from a mountaintop transceiver using license-exempt, 5.7 and 5.8 GHz spectral bands in an orthogonal frequency division multiplexing (OFDM) transmission. The OFDM technology makes efficient, and secure, use of spread spectrum by dividing data into packets and encoding it over multiple frequencies.

Point-to-point transmissions of this distance are not uncommon for rural WISPs. Under Part 15 rules for unlicensed usage, the FCC allows operators to make point-to-point connections without reducing Transmitter Power Output (TPO) for the 5.725 GHz and 5.825 GHz band. Because of this regulatory latitude for narrow beam transmissions, providers are able to reach long line-of-site distances with relatively low power.

The Roadstar network then reaches strategically placed wireless access points mounted on customer silos, barns and rooftops. To reach the last mile, Roadstar and other WISPs are able to transmit distances greater than the 300-foot standards for Wi-Fi, 802.11b technology by creating sectorized cells with high-gain, directional antennas. These last-mile connections on the 2.4 GHz band are the result of good planning and engineering, and typically reach two to three miles.

The unlicensed approach, on the other hand, already has been highly successful for extending wireless Internet connections to public spaces and private "hot spots," such as hotels, airports and coffee shops. As an application, Wi-Fi has been about linking users to the last few hundred feet or less of the last mile. This is a very important part of the last mile, but it is not the last mile itself. Only WISPs, which concentrate their limited power over longer distances using directional antennas, have made a serious attempt at providing a last-mile link to the fiber optic backbone. In addition, there have been some attempts to link Wi-Fi type nodes together to form a greater share of the last mile (both approaches are described below).

The ability of entrepreneurial WISPs to freely share unlicensed bands to deliver last-mile broadband connections has the added appeal of reducing the monopoly power of local cable and phone companies. The FCC's role is limited to setting standards for the transmitters and requiring that they be tested for compliance before sale.[13]

Low power, unlicensed devices have been more decentralized and competitive than their licensed counterparts. The philosophy of unlicensed is to "let a thousand flowers bloom." That is, barriers to entry are minimal. In any given unlicensed band, different manufacturers and standards can freely compete. The result has been an explosion of consumer choice and innovation. Today, the average American has many more unlicensed than licensed radio devices. These include one-way remote controls (e.g., for televisions, garage door openers, car doors, toy cars, home security, and wireless computer keyboards), sensors (e.g., light and alarm motion detectors, ground penetrating radar, radiofrequency identification on merchandise, and automatic toll booth collectors), and two-way communications devices (e.g., Wi-Fi, family walkie talkie, and Bluetooth).

Somerset County, Pennsylvania:
A Model for Bringing High-Speed Wireless to Rural Schools and Communities

As the Superintendent of the Rockwood Area School District, Andy Demidont's goal was to "leave no child behind." But in this mountainous, rural section of southern Pennsylvania, the schools and local residents had no cable or DSL access and only the slowest dial-up connection. So the school administrators looked for an alternative solution – one that would bring broadband Internet to both the elementary and high school, and also to the parents in their homes. With help from Sting Communications, a Pennsylvania WISP, and using grant money awarded from the Individuals with Disabilities Act, the school district has built a wireless network that connects schools and homes in a high-speed network.

Simply bringing the technology to the area wasn't the end goal – using the network to connect the school with the community is the ultimate design of the project. Both the Rockwood and Kingwood schools have put many classroom and administrative operations on-line. Teachers use Palm Pilots and laptops to track student progress, design lessons and tests, and record grades – which are available to parents online. Students can use the high-speed connection in each classroom, with the entire school "unwired" for access.

Sting Communications has installed three towers to access the 5.8 GHz license-exempt bands. The Rockwood High School gymnasium hosts a 100-foot tower that transmits to a 150-foot tower located at Kingwood Elementary school 12 miles away. The two towers share a narrow beam, point-to-point connection with a third tower owned by the local Seven Springs Ski Resort. Within this triangle, multiple access points within neighborhoods receive directional signals, and transmit in efficient, pie-shaped sectors that cover much of the mountainous community. The last-mile connections in homes and classrooms travel on the 2.4 GHz license-exempt frequencies.

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The purpose of the low power limits on unlicensed devices is to avoid interference with other users of the same spectrum who operate at higher power levels. Yet, low power has two other important advantages that may help explain its success. First, it allows for the massive reuse of spectrum. Fifty years ago, a single tower would provide mobile telephone service to an entire metropolitan area. Today's mobile telephone services may have hundreds of cell towers in the same area, with each tower allowing for the reuse of spectrum for additional telephone conversations. With tiny Wi-Fi cells—each home its own tower—capacity can be increased by three or more orders of magnitude.

Second, many unlicensed devices, such as TV remote controls, Bluetooth enabled PDAs, and cordless phones, are battery-powered. The low power conserves the batteries. What is more, the low power means a device will not interfere with a similar device on the same frequency a few hundred feet away. The power limits in the unlicensed bands are generally 1 Watt, but most consumer products operate well below this maximum since they are intended to operate on battery power inside the home.

Wireless Broadband Technology

Surprisingly, despite their huge regulatory differences, the basic technologies of licensed and unlicensed approaches are largely the same. The key resource of a wireless broadband system is spectrum. The technical properties that make a frequency work well for a licensed broadband service are the same as those needed by unlicensed networks.

The vast majority of spectrum (above, roughly 3 GHz) is line-of-sight. This means that obstacles, such as hills, buildings, and foliage, block signals. As a general rule, lower frequencies can penetrate objects more easily than higher frequencies. A higher frequency antenna in the home that requires line-of-sight needs to be placed in a window or on an exterior

Somerset County, Pennsylvania
(from page 6)

As an incentive to bring local businesses and residents onto the system, Sting has offered the fee of $10 per month plus an additional $10 equipment rental for the first 100 subscribers to the Rockwood network. For businesses that subscribe to the service, the schools' monthly access rates are discounted by 50% of their subscription rate.

The initiative has generated a great deal of interest in the community, and the school has collected a list of 100 households who would like to subscribe. Currently, thirty-five families have been connected, with the first 100 families expected to be online by the end of the summer.

Remaining residents will be connected to the network using 900 MHz "frequency hopping" radios. Frequency hopping transmitters use multiple unlicensed bands to find the most appropriate frequencies to reach subscribers. For densely wooded areas, such as Rockwood, the 900 MHz transmitters have better propagation characteristics, as lower frequencies can cut through foliage and find users in hilly terrain. Alvarion, one of the largest providers of fixed wireless technology, makes the new 900 MHz radios, which will be released in the coming months.

Project leaders hoped their last-mile approach could be replicated in other rural communities. Building on what they have learned, Sting Communications is working with school districts in Cambria and Clearfield Counties to implement the Rockwood model there. The school districts from the two counties have created a non-profit organization, BRAIN (Broadband Rural Access Information Network) to organize local resources and prepare the schools and residents for the network. This larger effort will connect 15 rural schools with community residents, and may provide a valuable last-mile case study for municipalities around the country.

surface. An example of a line-of-sight service is DBS, where the satellite dish must point directly to the satellite without any obstructions. Signals transmitted on low frequencies also require less power to travel similar distance.

In the unlicensed bands, transmitter power is generally limited to 1 Watt.[14] As stated earlier, Wi-Fi and other unlicensed devices for home use operate at even lower power.

The power of a transmitter can be distributed in two basic shapes: a circle and a line. An omni-directional transmitter distributes power in a circle; a directional transmitter distributes it in a particular path. A low power omni-directional transmitter, such as the typical home Wi-Fi device, may distribute power in an area no larger than a house or living room. A low power directional antenna may distribute the same amount of power over many miles—but only in one direction. Wireless unlicensed providers (WISPs) are able to provide unlicensed last-mile broadband service well beyond the confines of a home in part because they focus their limited power in a specific direction (see sidebars). When high performance directional antennas are used at both ends of the transmission for so-called "back haul" carriage of signals, a 1 Watt signal can have a range of 18 miles.[15]

As an analogy, think of a 100 watt light bulb radiating light at night in all directions. At a distance of 100 feet away, the received light is negligible. A laser with less than a millionth of the light bulb's energy can send an equally strong signal to a single point at the hundred-foot periphery. Alternatively, think of a ball of string. The same ball of string that can fit in your palm may unravel to thousands of feet when placed in a linear configuration.

Scaling Up Unlicensed: From Hot Spots to Hot Zones

Today, when many people think of unlicensed Wi-Fi, they think of hot spots at Starbucks for yuppies. But this is a deeply misleading image. Indeed, it is a classic example of misconstruing the power of an early technology by looking at its initial, primitive application. For example, when the telegraph and computer were first developed, few people, if any, had an accurate idea how they would be eventually used. Both were clumsy instruments primarily used by narrow elites (the federal government) for narrow purposes (the military). Similarly, we can already see that the Starbuck's "hot spot" is a grossly constrained vision of the future of wireless networking.

The challenge for the unlicensed approach has been to scale it up for last-mile use. There are three primary ways this is being done: through hot spots, hot zones, and hot pathways. A hot spot is a single low power access point, through which multiple users can share a broadband connection. A hot zone is a contiguous cluster of hot spots. A hot pathway is a link between hot nodes or zones.

The entrepreneurial inventiveness in transforming low power unlicensed into an ever-increasing part of the last-mile broadband solution has been breathtaking.

Companies, universities, hospitals, and government agencies are knitting large campuses together with meshed networks of unlicensed devices. Where a road, wall, or other obstacle intervenes, they aren't digging up the road or tearing apart a wall to lay wire. Nor are they buying a license from the FCC. Instead, many opt to use an unlicensed device to complete the link.

In the United States, tens of thousands of unlicensed hotspots at restaurants, hotels, and transportation nodes are being knit together into a network to provide much higher speed broadband service than is available with even next-generation mobile telephone service. Many believe that these hotspots will serve the bulk of America's needs for high-speed broadband connections outside the home or office. For example, road warriors who rely on their laptops and e-mail for most of their communication won't need to rely on licensed mobile telephone airwaves. Next-generation mobile phones, PDAs, and laptops will be Wi-Fi enabled. Phones will default to a low-cost, high-speed Wi-Fi mode unless Wi-Fi service is not available in a particular place. This helps explain why mobile telephone carriers have lobbied against more unlicensed spectrum, and one major carrier sought to abolish it altogether.[16]

When many hot spots in a specific geographic region are tightly linked together, they become "hot zones." In France, the 400 stations in the Paris Metro system are each being given a cluster of Wi-Fi hotspots. Eventually, each train on the metro will also be turned into a hotspot. When the system is completed, the Paris Metro will be a hot zone[17].

Some communities in the United States, including San Francisco, are providing hot zones in downtown areas as economic development tools. In Manchester, England, a low-income, depressed area, a six square mile area is becoming a hot zone (see the sidebar profiles below). The justification is that Wi-Fi costs less than conventional wired broadband service, so it is the only economical way to provide high-speed broadband connections to a poor area.[18] Some communities, such as Garden Grove, California, are building hot zones both within and linking government buildings, such as city hall and the police and fire departments.[19]

Broadland, Illinois:
Wireless Broadband for the High Prairie

There is little incentive for telecommunications and cable companies to bring high-speed Internet to towns as small as Broadland, Illinois, population 350. However, the local farmers of this town have a great need for high-speed access to monitor their markets and manage their businesses. To meet that demand, Prairie iNet, a Des Moines, Iowa WISP, has built a wireless network for rural residents in Broadland, as well as 120 other communities in Illinois and Iowa.

Prairie iNet relies on the existing infrastructure of the high plains, with local silos, barns and rooftops serving as towers for the company's point-to-point and point-to-multipoint transmitters. With a coverage area spanning over 10,000 square miles, over 4,000 users receive high-speed connections via 100% license-exempt spectrum.

The company uses the 5.3 and 5.8 GHz frequencies for tower-to-tower and backhaul transmissions, while the last-mile connections to users are typically well over a mile, and on the 2.4 GHz unlicensed band. The wireless network eventually connects to the Internet pipe via a DS3 fiber line at the Prairie iNet command center.

Dennis Riggs, a Broadland native and one of the founding partners of Prairie iNet, says that selling high speed Internet connections to people who live beyond the reach of wired providers is "one of the easiest things [he's] ever done."

One means to link unlicensed hot spots is via conventional transportation. In India, the government has placed unlicensed devices on public buses and allowed all Wi-Fi devices to operate at higher power than allowed in the United States. When a bus drives by a neighborhood, it wirelessly updates and is updated by all the Internet accounts in the neighborhood. When the bus drives by a backbone node, it wirelessly updates and is updated by the rest of the network. This is only useful for asynchronous services such as e-mail and downloading applications. But it is a very inexpensive way to create ubiquitous Internet and broadband access. A comparable wired network could cost hundreds of times as much.

One variation of transportation-based linkage is for public safety vehicles. Conventional police communication devices employ low bandwidth radio. Today, some police departments are creating hot spots so that police can drive to certain locations within their beat and quickly download or upload whatever information they want.[20]

Another variation of transportation-based linkage may soon be ubiquitous in America. Cars may soon have Wi-Fi devices built in them. Music selections, audio books, and other content may be downloaded from a home computer and wirelessly loaded into the car's computer system. The car may also become one of the means by which office work travels back and forth to the home office.

Similarly, children may wirelessly download their school homework assignments into a small, inexpensive device that links to their home network when they arrive home. Many school networks today run at 1 Gbps, approximately a thousand times the speed of a typical home wired broadband network, or 20,000 times the speed of the fastest dial-up modems.

Libraries, public parks, and other hotspots may serve not only as information destinations but also as delivery vehicles for portable wireless devices to pick up and drop off information.

MIT scientists are developing "viral networks" of unlicensed devices. Since every unlicensed device allows the reuse of the entire electromagnetic spectrum, the total information carrying capacity of a network is proportional to its number of nodes. As more unlicensed devices are added to the network, the capacity of the network increases. The United States military has been most aggressive in implementing such viral networks. Each soldier becomes his own portable cellular transmitting and receiving tower—a cell tower on legs.

Perhaps the easiest way to scale up a hot spot into a virtual hot zone is to increase the power levels of the hot spot to cover a larger geographical area. For example, shouldn't hot spots on the Mojavi desert or Alaskan tundra be allowed to cover more distance than a hot spot in Los Angeles or Manhattan? More generally, shouldn't the size and power levels of hot spots differ in urban and rural areas? The FCC clearly recognizes the deficiency of one-size-fits-all hot spots and has initiated numerous proceedings questioning whether unlicensed devices should use Global Positioning System (GPS) or other technologies to give them location-specific power flexibility. Many foreign countries with relatively little use of the airwaves already employ their own form of location awareness: they allow unlicensed devices to operate at greater distances than in America.

Scaling Up Unlicensed: Hot Pathways for Last-Mile Backhaul

The other major way to provide unlicensed service over large distances—"hot pathways" —is to pinpoint transmitting and receiving equipment. Today, some transmitters send signals in sectors as slender as 1 degree (for those needing a refresher, a circle has 360 degrees, a right angle a sector of 90 degrees).[21] If information is directionally transmitted in pencil-shaped beams between two points, the spectrum in a three dimensionally defined area is virtually limitless, since there are an infinite number of directions available for communication. Think of thousands of laser beams passing through each other in the night to get to their destinations as opposed to one giant floodlight lighting up the landscape in all directions.

The use of hot pathways allows unlicensed information to travel many miles without creating unacceptable interference. This is central to the success of WISPs because it allows them to take a low power transmitter and cover a long distance. WISPs have been especially successful in rural areas because it is prohibitively expensive to provide broadband wireline service in such areas.[22] For example, in the hilly terrain of Northern Virginia, two such WISPs (profiled in the sidebar above) use unlicensed spectrum to provide high-speed connections to farms, homes and businesses as far as 27 miles from the firm's fiber access point to the backbone.

> **North Texas Panhandle:**
> *Rural Wireless Broadband at DSL Prices*
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> With over 4,000 users on their license-exempt wireless network, AMA.TechTel Communications of Amarillo, Texas is one of the country's largest WISPs. Like many larger providers, they have roots in dial-up and DSL. But in recent years, they've benefited from the relative ease of fixed wireless deployment to reach rural markets craving high-speed access.
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> AMA entered the WISP business when a large grain storage company, Attebury Grain Inc., asked them to connect their grain elevators to the commodities market. After exploring different solutions, they decided a wireless network made the most economic and technological sense. Partnering with Attebury, they saw an opportunity to widen the network and provide wireless access to communities within the footprint of the elevators.
>
> Like many larger WISPs, their customers are a mix of households and small and large enterprises. Using a mesh-network of Alvarion transmitters operating on the 5 GHz unlicensed bands, AMA has created secure, private environments for three college campuses and two banks. AMA has grown rapidly in the past two years, recently enlisting 150 new users a month with very little marketing.
>
> The north Texas network extends over two and half hours from Amarillo. For their rural customers, unlicensed wireless helps to even the economic playing field as these customers pay roughly the same rates for similar service as urban DSL subscribers.

One vendor, Alvarion, has installed 800 such unlicensed systems in the United States of which 130 are carrier and utility networks.[23] AMA.TechTel in rural Texas, is another example. It boasts 4,000 users with prices and speeds equivalent to DSL —which isn't available in most rural Texas communities (see sidebar above). Santa Ana Pueblo in New Mexico has installed a last-mile wireless broadband system on the unlicensed bands with the help of a grant from the National Telecommunications and Information Administration of the U.S. Department of Commerce. School systems in five Georgia counties with help from the Georgia Tech Research Institute have built wireless systems in the unlicensed band to deliver broadband to schools. In Japan, Tokyo Electric Power uses Alvarion technology to deliver wireless broadband from access points affixed every half mile to fiber optic lines on its poles.

Government statistics on the number of such small wireless systems are not available because they fall outside the scope of the FCC's broadband reporting requirements.[24] However, in a separate report on fixed wireless, Commission staff has noted outside estimates of between 100,000 and 300,000 subscribers to broadband service in the unlicensed bands.[25] Other research estimates the number of fixed wireless broadband subscribers to be considerably higher. The technology market research firm In-Stat/MDR estimates there are between 1,500 and 1,800 WISPs in the U.S. with a total number of users reaching over 800,000.[26]

San Francisco, California & Roxbury, Massachusetts

Community Access Models for the Last Mile

While the success of commercial WISPs has generated much attention, grassroots community access networks or CANs are the originators of the unlicensed movement. Most CANs are groups of like-minded individuals sharing a similar philosophy—that citizens should and can have open, inexpensive, and ubiquitous access to the Internet. Using affordable and easily installed Wi-Fi technology, community members in Seattle, New York, Austin, San Francisco, Portland, Oregon and Athens, Georgia have built expanding networks of independently maintained wireless access points that are shared among many.

Most CANs provide access to people in public spaces, such as parks, commercial zones and retail locations. However some groups have made forays into the residential space, by connecting neighborhoods and apartment buildings with centrally placed access points. Two diverse models for spanning the metropolitan last mile are demonstrated in very different contexts: the first is in the more affluent San Francisco Bay Area, and a second in a low-income apartment residence in Roxbury, Massachusetts.

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In the future, the development of smart antennas may make possible the creation of mobile hot pathways. Arraycom has already developed such a technology. Transmitters and receivers have enough intelligence that the pathways can follow the person.

The Future of Broadband

The speeds of today's last-mile broadband service are clearly inadequate for the needs of the future. Recognizing this, the high-tech industry has been calling for dramatic increases in last-mile broadband speeds. Technet, a large coalition of high tech CEOs, has called on federal policymakers to make next-generation broadband a national priority and set a goal of making affordable 100 megabit broadband connections available to all American homes and small businesses by 2010.[27] The Computer Systems Policy Project (CSPP), made up of the handful of elite computer manufacturers in the United States, has endorsed the Technet goal.[28] The State of California has funded a non-profit entity, CENIC, to pursue an even more ambitious goal: one gigabit broadband to all Californians by 2010.[29] More recently, three of the largest U.S. telephone companies, SBC, Bellsouth, and Verizon, have formulated a fiber-to-the-home standard and asked equipment vendors for the cost of bringing fiber to every American home.[30] A single strand of fiber today can carry 10 gigabits/second.

What will be done with all this capacity? No one knows for sure. But 25 years ago when personal computers typically had less than 512 kilobytes of memory and processors that ran slower than a megahertz, people could not have conceived what could be done on today's personal computers that often have more than a thousand times the memory (512 megabytes) and a thousand times the speed (1 gigahertz). One can imagine, for example, that video conferencing for education, work, and e-commerce, including healthcare and other services, will become pervasive. Meanwhile, the resolution expected in videoconferencing will increase from standard resolution TV (about 1.5 Mbps) to today's high definition TV (about 10 Mbps) to the emerging cinema standard (about 200 Mbps).[31] For two-way communication, this data rate needs to be doubled. And if multiple members of a household are simultaneously communicating with the outside world, the data rate needs to be increased that much further. Most computers today have video cards with resolutions higher than HDTV.[32] As Cenic's February 2003 report, *One Gigabit or Bust: Killer Apps—Proving the Need for One Gigabit*, concludes: "For videoconferencing to reach its full potential, the technology will need gigabit connectivity…." (p. 9).[33]

San Francisco, California

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A Community Access Model for a Middle Class Area. The Bay Area Wireless Users Group (BAWUG) is an elder organization in the world of community access networks. As early as 2000, San Francisco area residents began mounting Wi-Fi transmitters on the roofs of their homes to give neighbors free or shared-cost Internet connections via their DSL and cable lines. While the cable and phone companies didn't approve of the practice, consumers did and CANs began popping up all over the city.

Now, three years later, BAWUG wants to expand the CAN model to bring more users inexpensive, high-speed, wireless access. Tim Pozar, a telecommunications engineer and one of BAWUG's founders, has launched the Bay Area Research Wireless Network (BARWN). BARWN is an active wireless network and ongoing experiment designed to discover the best implementation strategies to bring wireless broadband to remote and economically disadvantaged communities.

BARWN has set up a long-distance, line-of-sight link connecting downtown San Francisco to an access point atop San Bruno Mountain. Anyone within an 8-mile radius can direct a 2.4 GHz antenna at the access point to share the 11Mbps of bandwidth provided by the tower. BARWN uses non-proprietary equipment and open protocols to keep costs down so that lower income communities can replicate and adopt the BARWN protocols.

As evidence of the system's technological stability, BARWN is discussing plans with the City of San Francisco to use this network for public safety communications—such as earthquake or disaster response. Pozar says one application for the unlicensed service would be to provide streaming video of a disaster site to command centers to evaluate response tactics.

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Another use for all this capacity is for the ubiquitous links and sensors that are expected in the house and business of the future. Many houses today, for example, have dozens of cables linking devices. Not only is wireless expected to cut these cables but also it may link all consumer electronic, appliance, and computer devices in the integrated networked household of the future. The possibilities for sensors are also numerous. All electrical devices, for example, may monitor their own energy use and send the information to a centralized household energy database. Other devices may monitor for faulty or worn out parts. Internal radar, security devices, and weather sensors would generate continuous streams of data.

When gigabit speeds are affordable, customers clearly demand it. This explains the "last-mile speed gap." Gigabit or close to gigabit speed is already widespread in the backbone and within local area networks. It's only the gap between the local area network and the backbone that's stuck in single digit megabit or slower speeds. In the local area network, even the least expensive consumer PCs include Ethernet links of at least a 100 Mbps and USB 2.0 links of close to 500 Mbps. Ethernet is used to link computers to each other and USB 2.0 to connect computers to devices such as camcorders and printers. Gigabit Ethernet links are offered by all major personal computer manufacturers, are standard components in new business PCs, and can be added to many older PCs for about $50. Gigabit wiring to connect local PCs together can be purchased at Home Depot, Lowe's, or almost any hardware store for cents a foot. Experts predict that within a decade businesses will switch to 100 Gbps networking. A single strand of fiber today often runs at 10 Gbps, and the Internet backbone is full of such fibers. Many businesses and government buildings, including K-12 school buildings, now connect directly to these gigabit backbones.

Roxbury, Massachusetts
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A Community Access Model for a Low-Income Area. Far from the Bay Area, one low-income community is taking their own steps toward broadband access. Residents of Camfield Estates, a public housing community in the Roxbury section of Boston, have transformed their Neighborhood Technology Center into a wireless community access point. The goal is to build a CAN to deliver all 102 Camfield households high-speed wireless access.

The effort began as a by-product of a research study conducted by MIT graduate student Richard O'Bryant. The MIT researcher had been working with Camfield residents for three years learning how the Internet could be used to build community in low-income neighborhoods. During the project, 35 households received broadband cable Internet connections in their homes. But when the research ended, and the funding stopped paying for the expensive cable service, residents needed to find a low-cost and easily-implemented solution.

Acting on advice from Anthony Townsend, a founding member of NYCWireless (a large metropolitan area network), project leaders mounted a 2.4 GHz access point on the roof the Technology Center. The transmitter connects to the T1 line in the Technology Center to reach residents with wireless equipped computers in their apartments.

The Technology Center is researching which wireless cards and antennas will work best to help residents make the smartest upgrades for their computers. After making the one-time expense of installing a Wi-Fi card, Camfield residents will profit from the ubiquitous access offered to the community.

Will the gigabit broadband last-mile networks of the future be wired or wireless? And if, as we believe, wireless last-mile connections can be deployed more quickly and at lower cost, should the nation rely primarily on licensed (exclusive use) or unlicensed (shared use) access to the public airwaves to jumpstart broadband deployment?

Wireless vs. Wired Last-Mile Solutions: Cost and Quality Considerations

All over the world, places lacking an existing narrowband last-mile wireline infrastructure are installing wireless technologies because these technologies are less expensive and offer users more mobility. Narrowband is defined as conventional, plain old telephone service quality—less than 56 kilobits. In China and India, for example, more individuals use mobile phones than wireline phones. In Iraq, America is investing in mobile telephone service for Baghdad, not wireline service. Even in the United States, where there is already a vast installed wireline network, many citizens are dropping wireline service for wireless service because they want the mobility that wireless service offers.

But licensed high-power wireless providers are having a hard time scaling up to today's typical wireline broadband speed of even just 1 megabit. Mobile telephone companies plan to upgrade their networks to third-generation cell phone technology, or 3G, which operates at a maximum of 2 Mbps in a stationary mode and 0.384 Mbps when in motion and which, if these speeds were actually achieved,[34] would be on a par with current wireline broadband Internet service. But they also claim that they don't have enough spectrum to provide broadband service at higher speeds. What happens when they must compete with gigabit service? Will they need a thousand times the spectrum they currently have? Clearly, some fundamental changes will have to happen if wireless is going to be competitive with wired in the emerging gigabit broadband world.

Manchester, England

Unlicensed Broadband is Not Just for Yuppies Anymore -- It's an Appropriate Technology for Underserved Urban Areas

While policy makers in the U.S. debate over how to bridge the last mile, unlicensed technology is giving disadvantage communities the ability to confront and solve access issues for themselves. One shining example is the case of the EastServe network in East Manchester, England, where community members have installed a wireless broadband network connecting 350 households, 17 area schools, and nine community technology centers.

The EastServe network was created by residents from the towns of Beswick, Clayton and Openshaw through the British government's "Wired Up Communities" initiative, which pulls public and private entities to bring broadband Internet to disadvantaged areas. There are seven pilot communities across England in the Wired Up Communities initiative -- each of which is using a slightly different technology or implementation model to learn the best strategy to reach the UK last mile. EastServe is the flagship project for unlicensed wireless broadband, and a showcase for unlicensed wireless in urban areas.

For East Manchester, wireless was the only viable solution. Ninety percent of the population have no high-speed cable access, and 25% have no fixed-line phone service since many households only use mobile phones. With 80% of the population living in houses, almost half of which are publicly funded, the expense of laying cable or a DSL loop to each residence is especially prohibitive. But a wireless solution, with its flexible and facile installation, allows community stakeholders to set-up, manage and trouble-shoot technical problems themselves.

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Gartner, a market research firm hired by Cenic, came to the conclusion that wireless cannot compete with wireline in a one gigabit world:

> To survive—and thrive—Gartner believes wireline carriers must use the current investment opportunity to deploy an unassailable competitive advantage. Now is the time to make an investment wireless providers cannot match because of wireless technology limitations… Clearly we believe enabling integrated Next-generation Broadband services is the key to survival for wireline providers.[35]

There is logic to this. If you assume high-power licenses covering large geographic areas, it's absurd to think that wireless could be a viable competitor to wired service. A licensed cellular provider that serves one thousand households via a single omnidirectional transmitter using 1 GHz of spectrum would only be able to provide, on average, 1 MHz of spectrum per household (and currently the entire cellular industry licenses only one-fifth as much spectrum). Or take an even more absurd example, which nevertheless more accurately characterizes today's power levels on the beachfront spectrum below 1 GHz. A licensed transmitter in New York City operating at standard TV broadcast power levels and thus covering more than 10 million households would only be able to provide, on average, 100 hertz to each of those households.

Manchester, England
(from page 15)

A local company, Gaia Technologies, has trained resident volunteers to install and maintain the 10 community access points currently in place. Volunteers from the neighborhoods will add an additional 15 access points in the next phases of the project. Over 700 households within a 6-mile area have signed up for the service, and project leaders estimate that with the ease of rooftop installation they can bring 100 new users per week onto the network.

Gaia Technologies Managing Director, Anas Mawla says the network is a ring formation of six backbone towers, which are located among the 17 schools and nine on-line centers on the network. These six towers provide a total of 26Mbits of data transmitted in narrow beam, point-to-point connections at 45 Mbps on the 5.8 GHz band. The backbone relies on a partial mesh design for redundancy. Proxim makes the 5.8 GHz transceivers.

Within this ring of towers, twenty-five 802.11b access points transmit in wedge-shaped sectors to reach households with up to 11 Mbps of data to be shared among users. EastServe uses Cisco Systems' Aironet customer premise antennas for the last-mile link to houses. Flat dwellers share a wireless link that connects directly to the backbone, demonstrating the network's scalability.

Since activating the network, the local telephone carrier has launched limited ADSL access to parts of East Manchester, however this service offers a much slower, asymmetrical service at higher prices than the EastServe wireless network. EastServe users also have access to a community Intranet; customer service provided by community members; and the ability to purchase new or recycled computers through the program. They also have the added comfort that they will soon own and maintain their network – no-longer at the mercy of a third-party provider to bring them the service.

The logic of this economic reasoning explains why licensed providers are continuously subdividing their licensed geographic areas and transmitting at lower power. By doing so, they can reuse spectrum and serve more customers at higher bandwidth. But if they are ever to achieve ubiquitous gigabit capacity within every household in America, power levels cannot get much higher than those for unlicensed today. And at these low power levels, unlicensed has already established a great track record of efficiency and innovation.

Similarly, for the last-mile link to connect the network within the home to the central office, there needs to be vastly increased spectrum reuse over today's standard. If a trunkline needs to provide gigahertz service to a thousand homes, for example, it needs a terahertz of spectrum—more than three times the ENTIRE radio spectrum!

To illustrate the relationships between power levels and next generation broadband spectrum use, consider three differences between existing Wi-Fi and cellular telephone service.

1. Wi-Fi is faster.

The present 802.11g standard for consumer Wi-Fi delivers three channels of information at 54 Mbps each to every U.S. household. In contrast, state-of-the-art, third generation cellular telephone service only offers speeds 1/100th as fast to a fraction of the households in their service areas. When more than a small fraction of individuals in a service area use the network, calls are dropped. On 9/11, for example, call volumes spiked and only a small fraction of callers could get through.

2. Wi-Fi uses less spectrum.

Wi-Fi delivers 100 times the speed with less than half the spectrum. Wi-Fi is allocated 83 MHz of spectrum and cellular telephone service over 150 MHz, almost twice as much.[36]

3. Wi-Fi devices are smaller and less costly.

Wi-Fi access nodes transmit at less power and can therefore use smaller, less expensive transmitters and batteries. One advantage of the new dual mode mobile phones that operate on both the low power Wi-Fi and high power mobile phone frequencies is that their batteries last longer when operating in Wi-Fi mode.

In short, until we are prepared to dig up every road, lawn, and wall in America to provide ubiquitous, next-generation broadband service—at a cost of hundreds of billions of dollars spread out perhaps over decades— we must rethink wireless policy.

The labor costs of installing wireless networks are intrinsically only a tiny fraction of the labor costs of installing wired networks.[37] The cable TV industry estimates that the labor cost alone of installing cable from the curb to the home is 45% of the cost of the entire last mile. This can largely be explained by the simple fact that the labor cost to dig a trench for 1,000 customers is no different than to dig a trench for one customer. Cisco estimates the average cost of installing 1 foot of fiber in the last mile in an urban environment is $110, while the cost of installing 1 foot of comparable wireless service in the last mile approaches $10.[38] Similarly, Endwave, Inc. estimates that wiring the 5.5 million major business locations in America with fiber optics at a speed of 1 to 10 gigabits would cost approximately $800 billion. Wireless technology could provide the same service for under $40 billion, a savings of more than $750 billion.[39] The savings from providing similar wireless last-mile service to more than 100 million United States households would be proportionately greater.

In addition to lower costs, wireless networks have the intrinsic advantage of being more convenient—a very valuable property for a communications network. Today, more Americans buy cordless than wired home phones--despite the fact that cordless phones typically cost twice as much—because they like the convenience of not being tied down to one spot or dragging a cord along with them. In the coming era of small Internet devices, they will want more of the same convenience.

However, if there isn't enough spectrum to provide the bandwidth needed for gigabit communication, the cost and convenience advantages of wireless may count for little. This is where spectrum policy reform must come into play.

Policy Recommendations

[T]he current debate over broadband has focused only on two platforms, Digital Subscriber Line, DSL, and cable and the regulatory treatment of those services. This perspective fails to consider that alternative modes or other technologies are available that can jumpstart consumer driven investment and demand in broadband services.

--Senator George Allen[40]

The current debate over last-mile broadband policy is all too often a sterile debate over policies related to the wired infrastructure. The debate needs to shift to spectrum policy. Spectrum is not just a third last-mile broadband platform to compete with cable modems and DSL. It should be the platform of choice. The wired infrastructure belongs in the backbone, not in the consumers home, lawn, or neighborhood. United States spectrum policy, however, appears geared to keeping the wireless alternative a crippled competitor to the wired broadband last mile.

Today's policy bias in favor of licensed, high power terrestrial transmitters may be costing the economy hundreds of billions of dollars per year. Cenic, for example, has estimated that a gigabit network could increase California's gross state product by $376 billion. Moreover, the health, education, and culture of our country are heavily dependent on the information infrastructure. To allow this infrastructure to continue to be polluted with today's government mandated, high power terrestrial transmitters is the industrial age equivalent of allowing factories and municipalities to emit their raw waste into our streams and fields.

Policymakers, including Congress and the FCC, should adopt spectrum allocation policies that allow wireless communication to be a viable competitor with wired communication in the coming era of gigabit service to the home. The continued existence of hegemonic high power terrestrial polluters is not consistent with this goal. Specific steps policymakers need to take include the following:

1. The FCC should allocate more unlicensed spectrum.
As information capacity needs increase and average power levels drop in coming years, the rationale for unlicensed spectrum increases. Only the low power levels conventionally associated with unlicensed can provide the information capacity the broadband network of the future needs. This is why descriptions of 4G (next generation cellular) and unlicensed technologies tend to overlap.[41] The underlying technologies of 4G and unlicensed are converging. The growth of dual mode Wi-Fi and mobile phones is merely step one in this process of convergence.[42]

2. The FCC should allocate more unlicensed spectrum at low frequencies (especially below 2 GHz).[43]
Currently, there is 26 MHz of long-term, dedicated unlicensed spectrum below 2 GHz, 180 MHz of licensed mobile telephone spectrum, and 402 MHz of licensed TV

broadcast spectrum. This amount of low frequency unlicensed spectrum is inadequate.

Spectrum at lower frequencies (below 800 MHz) is vastly more cost-effective for last-mile applications than is spectrum at higher frequencies. Information transmitted through spectrum at low frequencies can more easily pass through shrubs, walls, furniture, people, and other common last-mile impediments. One company has estimated that the cost of providing last-mile broadband service over frequencies as low as those used by VHF television stations (such as between 100 and 200 MHz) is several orders of magnitude less expensive than the cost of providing the last-mile service over a combination of high, microwave frequencies (e.g., the unlicensed bands at 2.4 and 5 GHz that WISPs use today).[44] Like TV broadcasters, last-mile providers could more cost-effectively transmit broadband access from a high building, tower or hilltop through the canopy of trees that surround many residential and business areas. Access to low frequency spectrum would also improve the mobility of last-mile connections, although the higher frequencies used for Wi-Fi today work well for short-range connections (such as within an establishment). Power and battery requirements to send the same information over the same distance are also much less.

Spectrum below 2 GHz may be especially important to link communications devices within the home or enterprise, and from the street curb to the home/enterprise. There are a vast number of obstacles within this space. This is also where the greatest number of wireless devices is expected to be located. Making low frequencies available will reduce the power requirements and enhance the portability of these wireless devices.

Low frequency spectrum is certainly available. Measurements of spectrum utilization in downtown Washington D.C. by the New America Foundation and the Shared Spectrum Company revealed significant "white space" (i.e., unused spectrum), most notably in the broadcast television bands allocated for Channels 52-69 (700 MHz band) and at even lower frequencies, particularly 200-400 MHz (where no utilization was detected).

Only four of the TV channels between 52-69 were even active in downtown Washington – which is one of the most intensely used airspaces in the nation – and only one station indicated a transmission above the minimum standard for protection from interference.[45] The New America Foundation further found that channels 52-69 were similarly underutilized nationwide. Each channel is assigned for high-power broadcasting in an average of only 10% of TV markets nationwide – leaving a vast wasteland of spectrum space available for sharing by "smart" broadband networks. This is precisely the kind of additional spectrum that would be most useful to last-mile broadband providers, since the lower the frequency the less expensive the infrastructure needed by a WISP or community network to provide last-mile service. This 108 MHz of spectrum could easily be opened for shared access by low-power, last-mile broadband providers and other compatible unlicensed services.

3. The FCC should allow more low power allocations of spectrum.
Currently, many bands of spectrum only allow high power use. This is akin to only allowing giant ocean liners to use the oceans, with all other vessels banned by fiat. These high power restrictions should be relaxed to allow for both high and low power use.

4. The FCC should charge license holders for exclusive rights to use the public airwaves for their most profitable use—low power transmissions.
Currently, incumbent license holders are furiously lobbying Congress and the FCC for "spectrum flexibility," including the right to use the public airwaves at low power levels without public compensation.[46] These highly valuable rights to use currently unused spectrum, called "white space," should not simply be given away.[47] They should be either auctioned separately (via an upfront payment or lease fee) or allocated to unlicensed use. With smart radio technology, low power uses can co-exist with high-powered uses. That is why the spectrum used by low power uses is called white space.[48] The FCC's Part 15 rules already allow for a particular type of low power sharing, called underlays, in many bands. But both underlays and low power sharing more generally need to be greatly expanded.

5. The FCC should increase power levels for unlicensed spectrum in rural and other sparsely populated areas.
Global Positioning Systems (GPS) and other new technologies make it relatively easy for unlicensed devices to acquire location awareness. In this new technological context, it makes no sense to require unlicensed devices to operate at the same power levels in Manhattan and rural Wyoming.

6. The FCC should allocate more unlicensed spectrum at higher frequencies for last-mile back haul.
At higher frequencies mobility is progressively lost but the cost advantage of not having to dig trenches to lay fiber in the last mile is still large. This makes high frequency spectrum well suited for last-mile backhaul from the home to the curb. High frequency spectrum is also well suited for reuse of spectrum via narrow pathways (also called "beamwidths"). Narrow pathways at low frequencies require much larger antennas than narrow pathways at high frequencies. The prodigious increase in spectrum capacity created by narrow pathways makes unlicensed an efficient allocation system for last-mile backhaul.

The FCC, for example, is currently allocating 13 GHz of previously virgin spectrum located above 70 GHz.[49] The Notice of Proposed Rulemaking describes this spectrum as a potential "replacement to fiber optics." Commenters describe the spectrum as extraordinarily well-suited for path-based spectrum reuse. Path-based spectrum reuse works best when it is possible to send narrow, point-to-point communications with relatively small antennas. Spectrum at these high frequencies can transmit for a distance of up to several kilometers, ample distance for a last-mile backhaul solution. Beyond that distance, atmospheric absorption weakens the signal to the point that it isn't currently practical to send and receive. This spectrum should be reserved for unlicensed use.[50]

7. The FCC should prohibit wired broadband providers—e.g., telephone and cable companies—from discriminating against unlicensed spectrum users. Restrictions on shared use were deemed unlawful with respect to the public switched network. They should be unlawful for the broadband network as well. Innovation will not flourish when it can be nipped in the bud by communications incumbents.

8. The FCC should develop a spectrum policy capable of supporting the XG type spectrum sharing technology developed by the Defense Advanced Research Projects Agency (DARPA).
According to DARPA, less than 2% of the most valuable U.S. spectrum capacity is currently in use. In other countries, the percentage may even be lower. The XG technology (XG is derived from neXt Generation) allows the U.S. military to share another country's spectrum without interfering with that country's domestic spectrum license holders. To disallow a similar technology in the United States would be to engage in a gross and embarrassing inconsistency—akin to the 1950s when the United States advocated democracy abroad but tolerated Jim Crow laws domestically.

9. High power transmissions need to be more heavily regulated than low power transmissions.
Because high power transmissions can do much more harm and be much more wasteful than low power transmissions, they need to be more heavily regulated. Today, the tendency is strongly in the opposite direction. Because high-power licensees got the initial rights to use frequencies and now wield substantial political power, low power users are being forced to accommodate them. Accordingly, high power users are given primary legal status and low power users secondary status. In the future, the relationship should be reversed.

10. The FCC should force high power polluters to become socially responsible citizens.
Currently, the FCC places the burden of non-interference solely on the low-power radios. In the future, the burden should, at a minimum, be shared equally. For example, high power transmitters that are "good citizens" should transmit their geo-location so that other transmitters can avoid interfering with them. Similarly, receivers for these high power transmitters should send out low power signals announcing themselves, just as tall buildings, boats, and cars are required to transmit light to signal others and prevent collisions. If high-powered users were good citizens, spectrum worth tens of billions of dollars would be freed up, and low power, low cost unlicensed use would be greatly facilitated.[51] Not all high-power users are polluters—any more than all tall buildings lack anti-collision lights at night—but the FCC has allowed high-power users to hog far more spectrum than they need.

Conclusion

Wireless is a huge whale floating just beneath the surface. All people are seeing is the tail fluke. But one day it's going to breach, and everyone is going to be surprised at the size of it.

--David Hughes[52]

Congress and the FCC are acting to lock in high-power, exclusive allocations of spectrum at the very moment that low-power, shared allocations are establishing themselves as the wave of the future. This is not deregulation but a disastrous and dated form of regulation.

Wireless technologies should play an important part of the last-mile solution. Too often the broadband debate today centers on competing wired technologies (cable modems and DSL) rather than spectrum policy. Yet wireless last mile providers are proving that unlicensed spectrum can be utilized to deliver high-speed Internet connections more quickly and cheaply, particularly in rural areas. And as the need for a gigabit level last mile becomes evident, spectrum allocations will need to favor low power use. This implies that the economics of unlicensed use are becoming increasingly favorable.

Unlicensed use has economic and social importance far beyond the benefits of stand-alone Wi-Fi hot spots. To equate Wi-Fi with unlicensed is to confuse the tip of the iceberg with the iceberg. The technology and protocols already exist to scale wireless broadband up from hot spots, to hot zones, to hot, last-mile pathways.

To be fair, almost no one in Washington DC is badmouthing low power, unlicensed use of spectrum. The success of Wi-Fi has made that an untenable position. But the effort to ghettoize Wi-Fi to the high frequency spectrum slums has been endorsed by incumbent spectrum licensees and is currently driving United States spectrum policy. If this effort is successful, it will be a disaster for next-generation broadband.

Speech, of which wireless telecommunication is its 21st century medium, should be returned to its birthright of freedom. Appropriate spectrum policies can make that happen. They can give consumers in rural areas and low-income areas the advantages of high-speed Internet access. They can allow wireless to become a viable, perhaps even superior competitor in the next-generation gigabit network. In the past, low power unlicensed uses of spectrum have been an after-thought, the second-class mammals in an age ruled by dinosaurs. In the future, they need to be primary, because the gigabit network of the future depends on them.

Endnotes

[1] The explanation is that the line is shared by neighbors; as more neighbors use the line, the speed slows down—sometimes to under 50 kilobits per second, less than one-fortieth of claimed speeds.
[2] FCC Industry Analysis and Technology Division, Wireline Competition Bureau, High Speed Access for Internet Service, Status as of June 30, 2002, Table 4, showing lines providing over 0.2 Mbps service in both directions.
[3] Cable industry statistics differ from the FCC's. They show 11.3 million cable modem subscribers. They also show that cable modem service is available to 80% of U.S. television households. NCTA Industry Statistics, State Data www.ncta.com (March 25, 2003)
[4] Madanmohan Rao, "Japan: The Birth of the Wireless Information Society," *Electronic Markets*, June 3, 2003. See www.electronicmarkets.org/files/cms/50.php.
[5] See "America's Broadband Dream is Alive in Korea," by Ken Belson and Matt Richtel, *New York Times*, May 5, 2003.
[6] Currently, Wi-Fi LANs operate at 11 Mbps and 54 Mbps. This is the network's capacity, which is shared by all users. The speed an individual user will experience will be lower, depending, among other things, on the number of other users on the network at a given time.
[7] From a technical perspective, last-mile wireless broadband will look like cellular telephone service with two-way broadband service to the home in a honeycomb pattern of cells. Wi-Fi takes on this appearance although because of its low power, the cells have a radius of only a few hundred feet. If a larger area is needed, multiple access points are deployed.
[8] The current unlicensed frequency bands are: 902-928 MHz; 2.4-2.4835 GHz; and 5.15-5.35 GHz; and 5.725-5.825 GHz.
[9] LMDS has received the most attention as a licensed, wireless last-mile service. However, other frequencies have been tried as well. See, Seventh Annual Report and Analysis of Competitive Conditions with Respect to Commercial Mobile Services, Appendix A (July 3, 2002) p. A-7.
[10] FCC Public Notice, March 26, 1998, LMDS Auction Closes.
[11] FCC Public Notice, May 14, 1999, Local Multipoint Distribution Service Auction Closes.
[12] Seventh Annual Report and Analysis, note 6 *supra*..
[13] The rules for FCC certification and use of unlicensed devices are contained in Part 15 of the FCC rules, 47 CFR Part 15.
[14] Above 50 GHz higher power levels are allowed, partly because high frequency signals attenuate rapidly.
[15] One physical characteristic of spectrum is that less power is needed at lower frequencies to cover a certain distance. Thus, two otherwise identical signals will travel different distances depending on the frequency used. For example, a 1-Watt signal at low frequencies can be the basis for a wireless broadband service area with a radius of several miles from a central hub. Many mobile telephones, located on low frequency spectrum, operate on only ½ Watt of power. At high frequencies, the radius would be much shorter.
[16] See Cingular comments in the broadcast unlicensed NOI. In general, mobile telephone operators have not opposed existing unlicensed allocations. But they have opposed additional dedicated unlicensed bands in the beachfront spectrum below 2 GHz—spectrum they want for 3G mobile telephone service. Currently, 180 MHz of spectrum is allocated below 2 GHz for mobile telephone service. Only 26 MHz of comparable unencumbered spectrum is allocated for unlicensed use.
[17] See "Paris-Wide Wireless Internet Hotspot 'Wi-Fi' Pilot Launched by City's Transport Authority, RATP Based on Cisco Technology," *Business Wire,* May 26, 2003.
[18] See "With Wireless, an English City Reaches Across Digital Divide," *New York Times*, May 31 2003, p. C1.
[19] Kurt Mackie, "5G Wireless Expands Citywide Network," *Broadband Wireless Online*, May 28, 2003.
[20] Jack McCarthy, "Wi-Fi on the Beat," www.infoworld.com, May 19, 2003, pp. 52-3.
[21] For a variety of reasons, narrow sectors or beamwidths work best at higher frequencies.
[22] See the sidebar examples in this paper of successful rural WISP efforts in Texas, Illinois, Iowa, Virginia and Pennsylvania.
[23] Other vendors/installers include Motorola, Nokia, SkyPilot, Etherlynx, and Dardin.
[24] See discussion in FCC Industry Analysis and Technology Division, Wireline Competition Bureau, High Speed Access for Internet Service, Status as of June 30, 2002.

[25] Seventh Annual Report and Analysis of Competitive Conditions with Respect to Commercial Mobile Services, Appendix A (July 3, 2002) p. A-7.

[26] See the online abstract and press release for the In-Stat/MDR report, "Unlicensed Spectrum Drives Wireless Broadband Infrastructure Beyond Wi-Fi" available at: http://www.instat.com/press.asp?Sku=IN020617WN&ID=517. Viewed June 6, 2003. Also see news coverage of this report, as reported in the March 3, 2003 Mercury News, available at: http://www.siliconvalley.com/mld/siliconvalley/5304676.htm. Viewed June 6, 2003.

[27] TechNet, "A National Imperative: Universal Availability of Broadband by 2010," January 15, 2002. http://www.technet.org/press/Press_Releases/?newsReleaseId=374

[28] Computer Systems Policy Project, "Building the Foundation of The Networked World," January 24, 2002, http://www.cspp.org/reports/networkedworld.pdf.

[29] Cenic, "One Gigabit or Bust Initiative – A Broadband Vision of California," May 2003, http://www.cenic.org/NGI/Gartner/Gartner_Short.pdf

[30] Kevin Maney, "Fiber-Optic Lines on Fast Track," *USA Today*, May 29, 2003.

[31] A high-end consumer grade inkjet printer now provides approximately 4800 X 1200 dots per square inch. That's about four times the resolution of an entire HDTV screen. If an HDTV screen is approximately 1000 square inches, then its average resolution is approximately 1/4000 of the resolution of the inkjet printer. The point of this calculation is not to argue that inkjet quality should not be the video standard of the future but that there is great room for improvement over today's video technology. None of this even calculates the data requirements of 3D or tele-immersion.

[32] Videocards routinely come with resolutions of 1600 X 1200. HDTV, at maximum resolution, is 1280 X 720 or 1080 X 1920 dots.

[33] See "One Gigabit or Bust: Killer Apps—Proving the Need for One Gigabit," February 25, 2003, Corporation for Education Network Initiatives in California (CENIC), Available at http://www.cenic.org/NGI/KillerApps.pdf. Viewed June 16, 2003.

[34] In reality, these are hypothetical speeds. As more people use the network, the speeds degrade. Actual 3G networks operate at much lower speeds.

[35] See "One Gigabit or Bust Initiative: A Broadband Vision for California," May 2003, Corporation for Education Network Initiatives in California (CENIC), Available at http://www.cenic.org/NGI/Gartner/GartnerFull.pdf. Viewed June 16, 2003.

[36] An additional 30 MHz has been assigned for mobile telephone service but is not in use.

[37] Another extra cost of digging trenches is additional liability. Wired telecommunications companies are liable if they hit a water main or other utility. A misplaced backhoe can potentially cause tens of millions of dollars of damage and liability. Fear of causing such damage increases labor costs and slows deployment.

[38] Comments of Cisco Systems, Inc., FCC Notice of Proposed Rule Making, "Allocations and Service Rules for the 71-76GHz, 81-86GHz, and 92-95GHZ Bands," WT Docket No. 02-146, December 2002, p 3.

[39] Comments of Endwave, Inc., FCC Notice of Proposed Rule Making, "Allocations and Service Rules for the 71-76GHz, 81-86GHz, and 92-95GHZ Bands," WT Docket No. 02-146, December 18, 2002. The figure of $40 billion was derived from commenter's estimate that wireless would only be 3-5% the cost of wired last mile deployment at gigabit speeds. Five percent of $800 billion is $40 billion. See also Debbie L. Sklar, "The Low-Down on Fiber," *America's Network*, August 1, 2001.

[40] Senator Allen's floor statement introducing the "Jumpstart Broadband Act," S 159, *Congressional Record*, January 14, 2003, p. S301.

[41] In *Brave New Unwired World* (New York: Wiley, 2002), Alex Lightman describes the need for 4G technologies as follows:

> "… 3G has been promising a 2 Mbps connection…. In fact, this describes a raw data pipe that is shared among all the users on a 10 MHz radio channel in one cell. If there are many users in your cell using serious business applications, downloading large files, streaming multimedia, or anything else 3G is supposed to deliver, then the data rate will drop sharply for everyone. The only remedy, using conventional wisdom, is to have fewer people allocated per base station, i.e., build more of them. In fact, some industry players have proposed surrounding us with small picocells placed every 10 meters."

[42] Neil Taylor, "Mobile Telephony's Fate is Inextricably Linked to Wi-Fi," *South China Morning Post*, May 6, 2003, p. 2.

[43]Various parties, including The New America Foundation et al, in the FCC proceeding on Additional Spectrum for Unlicensed Devices, ET Docket 02-380, have advanced proposals for doing this.

[44] The calculation was based on providing broadband service to residents of West Virginia. The comparison was between the cost of providing service via MMDS spectrum ($677/household) and VHS spectrum ($94/household). See Shared Spectrum Company, "Solving the West Virginia Broadband Access Problem Using Automated Secondary Spectrum Technology," paper presented to Office of Senator John D. Rockeller IV, July 16, 2001.

[45] Max Vilimpoc and J. H. Snider, "Unlicensed Sharing of Broadcast Spectrum," New America Foundation, Spectrum Policy Program, Spectrum Series Issue Brief #9 (June 2003). For more detail on the spectrum use measurements made in downtown Washington, D.C. see Mark McHenry, "Spectrum White Space Measurements," presentation to New America Foundation broadband policy forum, June 20, 2003. Both documents available at http://www.newamerica.net/index.cfm?pg=event&EveID=284.

[46] Other elements of "flexibility" include the ability to resell or rent licenses ("secondary markets"), permanent rights to spectrum (elimination of so-called "investment uncertainty"), and elimination of all service restrictions (elimination of so-called "red tape").

[47] The historic pattern is for Congress and the FCC to give away spectrum rights without monetary public compensation. Less than 2% of spectrum has ever been allocated via auction. In addition to charging for new spectrum rights, we believe that Congress should charge for the use of existing spectrum rights—just as it charges for the use of other publicly owned natural resources. For more details, see Michael Calabrese, "Battle Over the Airwaves: Principles for Spectrum Policy Reform. Spectrum Policy Program Issue Brief #1" September 2001, Washington, DC: The New America Foundation.

[48] An analogy to explain how low and high power communications can co-exist is the acoustic spectrum in a football stadium. During a football game, the announcer (a high power speaker) can speak at the same time that tens of thousands of fans are chatting with each other. The fan can choose whether to listen to the high power announcer or his low power neighbor. Similarly, a smart radio receiver can choose to listen to either the high or low power transmitter.

[49] FCC Notice of Proposed Rule Making, "Allocations and Service Rules for the 71-76 GHz, 81-86 GHz, and 92-95 GHz Bands," WT Docket 02-146.

[50] Most commenters on this NPRM argued for a novel licensing scheme with significant overlap with the unlicensed spectrum model. They argued for a strict spectrum etiquette, with no service provider allowed more than a 1% sector and a maximum amount of power. They also argued for a largely automated spectrum coordination process where applicants would enter qualifications and coordinates into a database, as well as pay an application fee to cover the cost of coordination, and get a license on a first-come, first-serve basis. We endorse the commenters' automated coordination proposal, but we disagree that the end result must be a free exclusive ten-year license with an expectation of renewal. Instead, we argue for a non-exclusive license. We agree that some businesses will need the reliability of exclusive licenses. But we disagree that they shouldn't pay a premium for this level of service and that there aren't viable substitutes, such as optical fiber, that could provide this level of service. In essence, commenters are arguing for a business subsidy; moreover, a spectrum subsidy that strongly favors *big* business. Following Eli Noam's proposal for congestion pricing, those who want an exclusive license for a limited duration should pay a market-based fee for this privilege. Commenters agreed that in the vast majority of cases, especially for residential use, congestion was unlikely to be a problem. As Cisco commented, "The narrow beamwidths and relatively short path distances will enable the deployment of [high frequency band] radios so densely that for all practical purposes scarcity need never occur in these bands" (p. 4). It was on this basis, that commenters made their case against both geographic licensing and licensed band managers. But they failed to follow out the logic of their own argument.

[51] A simple way to implement this proposal would be to include a geolocation provision in the FCC's DTV tuner mandate. For more information, see NAF et al. Comments and Max Vilimpoc Reply Comments on "In the Matter of Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band," FCC ET Docket 02-380.

[52] John C. Dvorak, "Wireless Whale," *Forbes*, March 5, 2001