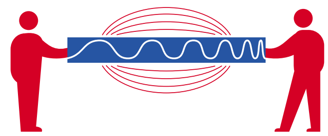
"They used to rob trains in the Old West.
Now we rob spectrum."
Senator John McCain,
Chairman, Senate Commerce Committee

An Explanation of

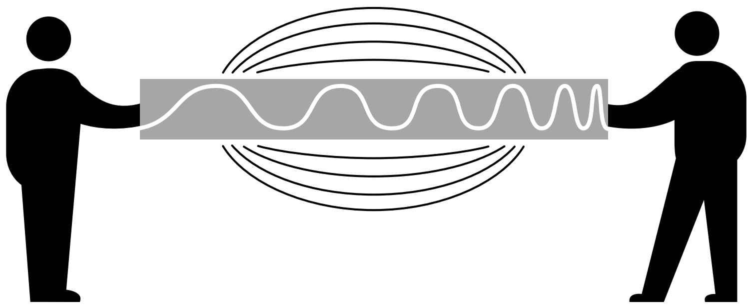


The citizen's guide to the airwaves

J.H. Snider
Senior Research Fellow
New America Foundation

"The wireless spectrum belongs to the public, and thus should be made to serve the public."
Senator Ernest Hollings, former Chairman,
Senate Commerce Committee

NEW AMERICA FOUNDATION
SPECTRUM POLICY PROGRAM



Explanation of

The Citizen's Guide to the Airwaves

J.H. Snider

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New America Foundation

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Washington, DC

Author

J.H. Snider, a former American Political Science Association Congressional Fellow in Communications and Public Policy, is currently senior research fellow in the Spectrum Policy Program at the New America Foundation. The author of numerous articles on information policy, he is a graduate of Harvard College and received graduate degrees in political science from Northwestern University and in business administration from the Harvard Business School. In addition to conceiving and coordinating this project, he served as project writer.

Contributors

Coleman Bazelon, former principal analyst in the Microeconomic and Financial Studies Division of the Congressional Budget Office, and author of numerous Congressional Budget Office spectrum valuations, is currently Vice President, Analysis Group. He provided economic advice and served as lead author of the "Marginal Flexibility Value" and "Universal Flexibility Value" subsections of the "Value of the Airwaves" section of this report.

Nigel Holmes, the former Graphics Director at *Time* Magazine and author of four books about graphics, including *The Designer's Guide to Creating Charts and Diagrams* (Watson-Guptill, 1990), is the principal of Explanation Graphics, www.nigelholmes.com. He designed the poster, and drew all the illustrations.

Bennett Z. Kobb, consultant and author of the definitive Wireless Spectrum Finder: Telecommunications, Government and Scientific Radio Frequency Allocations in the U.S., 7th Edition (McGraw-Hill, 2001), currently works at Obadal, Filler, MacLeod & Klein, P.L.C. He provided detailed information about federal and private sector frequency allocations.

Troy A. Kravitz, a summa cum laude graduate in economics from Emory University, currently works as a research assistant at the American Enterprise Institute-Brookings Institution Joint Center for Regulatory Studies. He served as this project's full-time research assistant, which included gathering and analyzing much of the economic and technical data.

Michael H. Rothkopf, an expert on the valuation of public assets, is currently a professor of management at Rutgers University. He provided economic advice and served as lead author of the "Current Use Value" and "Partial Flexibility Value" subsections of the "Value of the Airwaves" section of this report.

In addition, more than a dozen graphic designers, economists, engineers, and copy editors provided help on this project. Special thanks go to graphic designers Aaron Marcus (Aaron Marcus & Associates), Marti Hearst (University of California, Berkeley), and Ben Schneiderman (University of Maryland, College Park); Economists Howard Shelanski (University of California, Berkeley) and Shane Greenstein (Northwestern University); Engineers Bill Horne and Jim Chadwick (both from MITRE Corporation); freelance technical writer Kevin Werbach (Supernova Group); and copyeditors Max Vilimpoc, Hannah Fischer, and Michael Calabrese (all from The New America Foundation). Finally, dozens of citizens, chosen for their complete ignorance of spectrum policy, gave us feedback on the understandability of the poster.

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Contents

*Co-authored by Coleman Bazelon, Michael Rothkopf, and Troy Kravitz
**Derived from Kevin Werbach's "Open Spectrum: The New Wireless Paradigm," Spectrum Series Working Paper #6, Washington, DC: New America Foundation, October 2002.

Introduction

This document serves to clarify and expand upon the accompanying poster, The Citizen's Guide to the Airwaves. Additional copies can be purchased at www.spectrumpolicy.org.

Each era of humankind has a resource that drives wealth creation. In the agricultural era it was land; in the industrial era it was energy; and now, in the information age, it is spectrum, popularly known as the "airwaves." In recent decades, the value of spectrum has exploded. We estimate that the present value of the spectrum to those licensed to use it is almost $800 billion.[1]

By creating *The Citizen's Guide to the Airwaves*, the New America Foundation seeks to draw the American public's attention to the tremendous value, government mismanagement, and impending giveaway of this natural resource. Specifically, *The Citizen's Guide* makes four points:

- the public airwaves are immensely valuable,
- they are managed with gross inefficiency,
- they are a public asset being given away to large and wealthy corporations—perhaps the largest corporate welfare giveaway in the history of the United States, and
- revolutionary new technologies, such as "smart radio," are creating a need for new spectrum management policies—including more unlicensed spectrum, more frequency sharing, and shorter license terms—that can minimize spectrum scarcity and deliver low-cost, high-speed mobile Internet access.

The specific format by which spectrum information is conveyed to the public is also very important. In conveying information via a poster format, the New America Foundation has sought to create a new vocabulary to explain spectrum and spectrum policy. Here we have been inspired by the work of Yale Professor Edward Tufte, including his classic *The Visual Display of Quantitative Information*. Good information design is "clear thinking, made visible." It makes comparisons; shows causality; integrates word, number, and image; and is "driven by a deep and intense knowledge, and a deep and intense caring about the content."

Specifically, we looked at the current Department of Commerce spectrum chart and found it a paradigm of anti-Tufte thinking. The government chart could be viewed as modern art—full of dozens of bright colors, which made it a good wall poster—but it conveyed only one powerful message to the lay person: spectrum policy is too complicated for

"Spectrum policy was once an obscure abstraction for most Americans. But today Americans experience first hand the challenges of dropped cell calls—or limits on cable competition—or, for the early adapters among us, interference on their wireless LANs. These are no longer abstractions—they are spectrum policy problems."

MICHAEL K. POWELL, FCC CHAIR[2]

you to understand. We believe that's a terrible message to convey and probably not one its designers intended.

One of the most unusual features of *The Citizen's Guide* is its intended audience: the general public. The literature on spectrum and spectrum policy is vast. Hardly a month goes by without some think tank issuing a white paper on spectrum policy. And regulatory comments on spectrum policy filed by companies, academics, and others with the Federal Communications Commission (FCC), the National Telecommunications and Information Administration (NTIA), and Congress are vast enough to take a lifetime to read. Unfortunately, however, this information is not in a form usable by the general public, with the practical result that the public is excluded from political consideration when politicians formulate and enforce spectrum policy.

Meanwhile, at the other extreme of involvement is a small group of wealthy, technically proficient, and politically sophisticated insiders. They know that spectrum has already become worth hundreds of billions of dollars and in the near future may become worth more than all the gold ever discovered by humankind. This knowledge is manifested in the phalanx of wing-tipped spectrum lobbyists that incessantly walk the halls of Congress and the FCC.

Why is there such a huge discrepancy between what the insiders and the general public knows? Part of any explanation must include the fact that insiders have little incentive to disclose their information to the public, for the less the public knows about spectrum, the greater the insiders' ability to capture this vast spectrum goldmine for themselves. It's the same strategic logic that leads the goldminers in the classic Hollywood movie, *The Treasure of Sierra Madre*, to pretend to outsiders that they're not goldminers and have found no gold.

The combination of vast amounts of money at stake and general public ignorance creates the classic conditions for special interest politics to thrive. Indeed, spectrum politics may be the pre-eminent example of special interest politics in America today. Senator McCain has quipped: "They used to rob trains in the Old West. Now we rob spectrum." The difference is that while one form of behavior was outlawed, the other has been sanctioned by Congress. Senator McCain describes spectrum politics as the "poster child" of his concerns about the power of special interests in American politics.

Lack of public involvement also helps explain inefficient spectrum management. Absent public involvement, the government manages spectrum to preserve the profits and monopoly power of spectrum incumbents. This radically conflicts with the goal of efficient spectrum management.

Can the public really be brought into the debate over spectrum policy? We don't know for sure, but we certainly think it's worth a try. We especially hope the media will take up where we have left off. The spectrum policy story is one of the great dramas of our era. The challenge is to tell it in such a way that the public will listen and care.

Spectrum Basics[3]

To understand spectrum policy, it is useful to understand some basic concepts, including fidelity, waves, frequencies, signals, bandwidth, propagation characteristics, spectrum flexibility, and the difference between spectrum allocation and licensing. Readers may want to skip this section now and refer back to it only if additional background information is desired.

Fidelity

A slice of spectrum contains a band of frequencies. The wider the band, the more information-carrying capacity it has (it has more "**bandwidth**"). Bandwidth is generally counted in thousands, millions, or billions of hertz.

- **kilohertz** (1,000 Hertz) is written as kHz.
- **megahertz** (1 million Hertz) is written as MHz.
- **gigahertz** (1 billion Hertz) is written as GHz.

Note that convention dictates that kilohertz is abbreviated with a small k but megahertz and gigahertz with a capital M and G respectively.

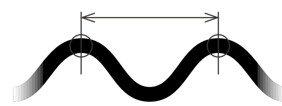
The greater the bandwidth of a communication, the greater its fidelity can be. **Fidelity** means the correspondence between the information at the sending and receiving end of a communication. Today, most wireless communication is low fidelity audio. In the future, high fidelity video could require 5,000 times or more bandwidth.

- 1 kHz — Text (e.g., closed captioned text)
- 10 kHz — Voice (e.g., telephone quality)
- 100 kHz — Music (e.g., CD quality)
- 1,000 kHz — Standard Definition TV (e.g., VCR quality)
- 5,000 kHz — High Definition TV (e.g., movie theater quality)
- 50,000 kHz — Super High Definition TV (e.g., glossy magazine quality)
- 100,000 kHz — 3D Super High Definition TV (e.g., glossy magazine quality 3D)

Waves, Frequencies, and Information

Electrical energy travels from place to place in one of two ways: it either flows through a wire or wirelessly via spectrum (popularly known as "the airwaves"). When electrical energy varies over time so that it conveys information, it is called a **signal**. Signals can either be analog or digital. **Analog signals** vary gradually between two electrical values; **digital signals** vary instantaneously.

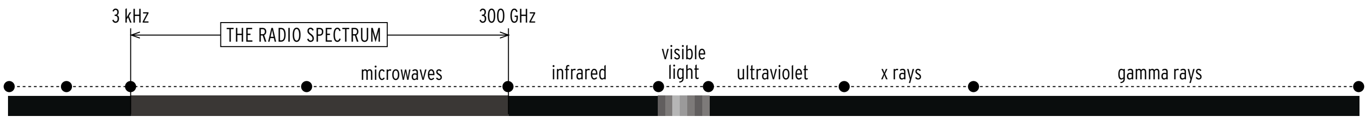
Electrical energy travels wirelessly in the form of waves, the basic information unit of spectrum. A **wavelength** is the distance between the recurring peaks of a wave. The number of times a signal goes through a complete up and down cycle in one second is the signal's **frequency** (measured in **hertz** and abbreviated Hz). For example, a 1 gigahertz signal goes through 1 billion cycles a second.



The electromagnetic spectrum has long wavelengths (low frequency) at one end and short wavelengths (high frequency) at the other end. The length of a wavelength affects a signal's **propagation characteristics**, including its ability to pass through objects.

As a signal passes through objects, it is gradually weakened. Although every object the signal encounters weakens it, some weaken it more than others. The air we breathe, for example, weakens it less than the drops of water in a rainstorm, which in turn weakens it less than a brick wall. This weakening is called **absorption**, and absorption tends to vary by wavelength. Long wavelengths (low frequencies) are less likely to be absorbed by dense objects such as clouds, trees, cars, and homes. This is a key reason that low frequency spectrum, such as the bands assigned to broadcasters, are most valuable.

Spectrum is divided into general bands based on wavelength. The portion of the spectrum valued most highly for communication purposes is the **radio spec-**



ELECTROMAGNETIC SPECTRUM

trum, located from 3 kHz to 300 GHz. Other well-known bands are the **infrared**, **visible light**, **ultraviolet**, **x-ray**, and **gamma ray**. It is illegal to use certain higher bands, such as x-rays, for communication because repeated exposure to x-rays harms human bodies.

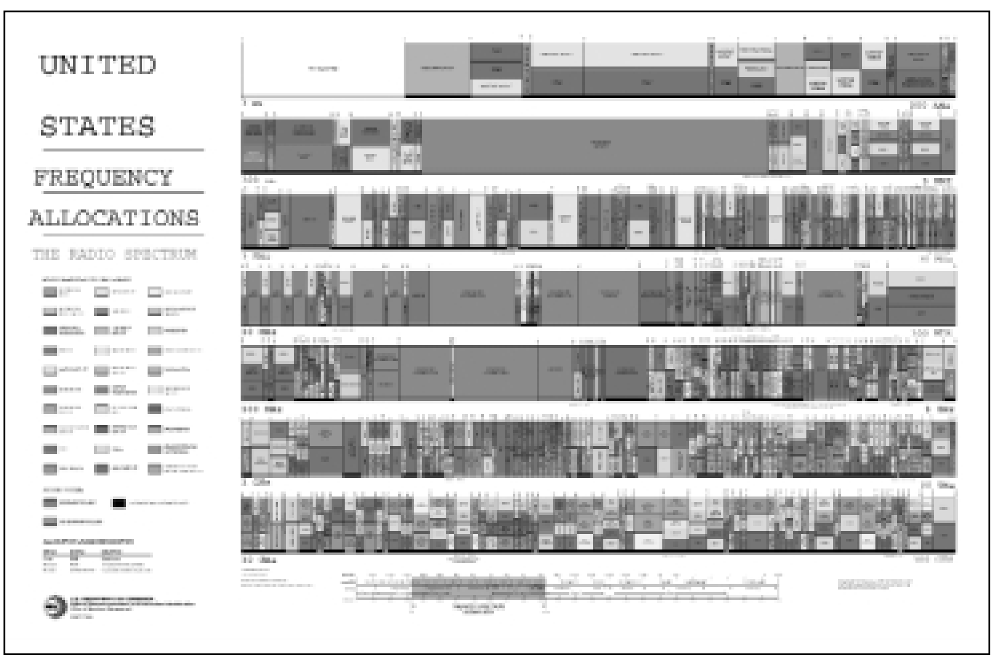
Spectrum Policy

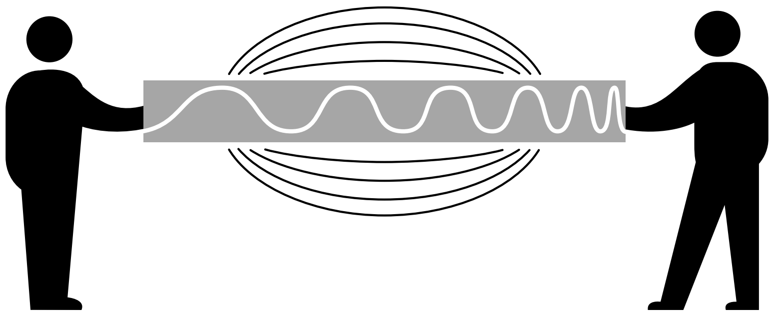
According to United States law, the public owns the spectrum; hence the well-known phrase "the public airwaves." The government manages the spectrum on behalf of the public by **allocating** spectrum for different uses. For example, it allocates frequencies between 174 and 216 MHz for TV broadcasting services (channels 7 to 13) and frequencies between 824 and 849 MHz for mobile telephone services. The United States Department of Commerce graphically depicts these allocations in a chart titled *United States Frequency Allocations*.[4] The chart divides the radio spectrum into more than 500 frequency bands, each of which may be shared by multiple types of allocation. Some users may be designated as **primary** and others as **secondary**. Secondary users may not interfere with primary users.

After the government decides what types of services are allowed in a given band of frequencies, it may **license** use of that band to specific entities such as broadcast companies, mobile telephone companies, police departments, and hospitals.

Allowing a licensee to provide additional services with a license is called **spectrum flexibility**. For example, a licensee restricted to providing mobile telephone service to taxi cab drivers wins spectrum flexibility when it is allowed to provide the service to all Americans, not just taxi cab drivers. Permanent, comprehensive spectrum flexibility is equivalent to **spectrum ownership**, which is illegal under United States law.[5]

The allocation and assignment of radio frequencies is limited by **interference**. Radio interference occurs when radio frequency energy other than a desired signal is present at the receiver. **Harmful interference** occurs when a desired and undesired signal both arrive at a receiver and conflict, such that the receiver can extract less information from the desired signal. It is important to understand that the level of acceptable interference is overwhelmingly a function of the equipment used, since simultaneous transmissions on the same frequency do not literally cancel each other out. High quality receivers can better discriminate between competing signals, thus mitigating the effects of interference. Disputes about interference, like lawsuits about land boundaries, are essentially disputes about who gets access to valuable property. In this case, the property is the information carrying capacity of spectrum.





PART I

Front Side of the Poster

Everyday Devices

Today, wireless devices are almost everywhere. It's hard to find a middle-class home in America without at least a dozen wireless devices (see "Licensed and Unlicensed Spectrum").

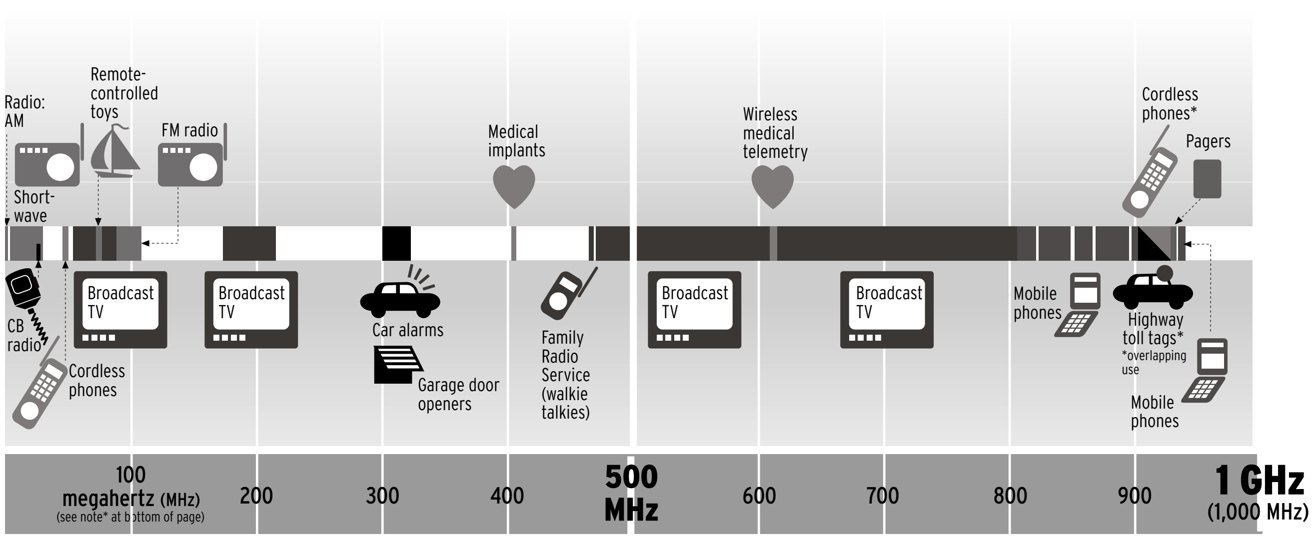
Despite the pervasiveness of everyday devices, they use only a small portion of the spectrum—less than a third of the most valuable spectrum under 3 GHz and less than 2% of the spectrum under 300 GHz.[6] The vast majority of spectrum is used by government or by industry in applications the consumer rarely if ever sees and in devices that consumers cannot purchase (see "Retail and Industrial Spectrum" and "Who Manages Access to the Airwaves?").

An **everyday device** is defined as one that could easily be purchased by a consumer at a mass market retail store such as Sears, Target, Best Buy, Circuit City, or Wal-Mart.

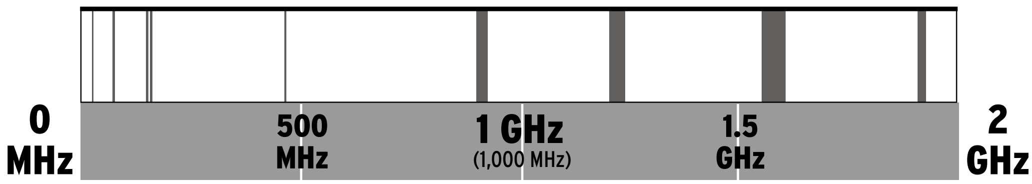
The line between everyday and other uses is not always easy to draw. We omitted wireless devices that may now be pervasive but which consumers cannot purchase at retail stores. These include the radar guns police use to catch speeding drivers; the traffic light cameras that catch drivers who don't stop at red lights; the automatic door openers used at the entrance of some retail stores; radar detectors at the entrances of airports and office buildings; and the handheld devices used by FedEx and UPS to digitize signatures and complete orders when delivering packages to your door.

There are also many everyday wireless devices that are not in the radio band (0-300 GHz). These include the infrared remote controls that today come with most consumer electronics products. Infrared remote controls require a short line-of-sight link to consumer electronics equipment. In the future, radio frequency remotes using Bluetooth and Wi-Fi (both at the 2.4 GHz band) are expected to replace many of the early infrared remotes.

In putting together our list of spectrum bands with everyday devices, we have overlooked the distinction between primary and secondary services. Many spectrum bands are allocated to multiple services. If there is a conflict with a secondary service, the primary service gets priority use of a band. Some everyday devices, such as broadcast television and mobile telephone service, are primary devices.



FREQUENCY ASSIGNMENTS USED BY EVERYDAY DEVICES



Citizen's Access Spectrum

Citizen access spectrum includes unlicensed, amateur, and personal radio services. Citizens can use citizen access spectrum without paying a fee or seeking the approval of a licensee. Whereas the ability to use other frequency bands is based on *exclusive licensing*, access to these bands is *open* and *shared*. These "citizen access" bands are either shared by consumer devices operating on an unlicensed basis (e.g., the unlicensed band at 2.4 GHz is shared by tens of millions of cordless phones, microwave ovens, wireless local area networks, such as Wi-Fi, and other devices), or shared by individual citizens (e.g., amateur radio operators) who qualify for an individual license.

The citizen access bar has two major differences with the everyday devices bar. First, it excludes services such as broadcast radio, broadcast TV, medical telemetry, and mobile telephone service that require some type of payment for spectrum use. Mobile telephone and medical telemetry service requires consumers to pay with money. Broadcast radio and TV require consumers to pay with time spent watching ads (the ad watching pays for the programming).

Second, it includes services that are not everyday uses because they are not readily available at retail stores, even though they can be used without a government license or fee to a private entity. This includes equipment to use some of the amateur bands, which requires additional effort on the part of the consumer to locate and use.

In putting together our list of spectrum bands with citizen's access, we have included bands that are not exclusively or even primarily for citizen's access. This tends to overstate the amount of spectrum allocated for citizen's access. For example, the Air Force uses the same spectrum band as garage door openers. The two applications can co-exist because garage door openers are low-power devices and are designed not to activate when an Air Force plane flies overhead.

Valuing Spectrum: Propagation Characteristics

In real estate, there is a famous saying that the value of a piece of real estate is determined by "location, location, location." With regards to spectrum, the equivalent phrase would be "frequency, frequency, frequency." Different frequencies have different propagation characteristics that have a huge impact on their market value. As a rule of thumb, the economic value of spectrum increases with its permeability (its ability to penetrate objects). This is reflected in the value chart, which shows that lower frequencies (longer wavelengths) are more valuable. The 1% of frequencies below 3 GHz are worth more than the 99% of frequencies from 3 GHz to 300 GHz.

We have divided the spectrum up into four zones: the permeable zone, the semi-permeable zone, the long line-of-sight zone, and the short line-of-site zone. As a rule of thumb, the permeability of a radio signal decreases as the frequency increases. [7]

FM radio (at 88 MHz) is an example of an application in the permeable zone. You can use your FM radio almost anywhere in your house without worrying that walls will block signal reception. A major attraction of modern mobile phones (which use bands between 800 MHz and 2 GHz) is their promise of anywhere, anytime accessibility.

Satellite radio service (at 2.320 GHz) is an example of an application in the semi-permeable zone. When you drive through an urban area with large buildings, your car's satellite radio may lose its signal but not its FM radio signal. Similarly, your mobile telephone (which uses frequencies as high as 1.99 GHz, on the edge of the semi-permeable zone) may be unusable while your FM radio continues to work perfectly.

Satellite TV service (at 12.2 GHz) is an example of an application in the long line-of-sight zone. The TV signal can go 22,000 miles between the satellite and your receiver as long as nothing is in-between. A tree or even a heavy rainstorm will block the signal.

Presently, we know of no widely used consumer devices in the short line-of-sight radio frequency zone. But consumer remote controls thrive in an environment that only allows short line-of-sight optical links. Many remote controls use infrared frequencies, which are located directly above the short line-of-sight frequencies. A standard called IrDA (which stands for Infrared Data Association) uses infrared signals to connect computer equipment such as personal digital assistants, keyboards, mice, and printers over distances less than 3 feet. The short communication distance and difficulty penetrating walls is considered a plus because it enhances security and allows many computer devices in the same room to reuse the same frequency.

In reality, we have greatly oversimplified the ways in which propagation characteristics vary over frequency. For example, antenna size increases with lower frequencies. At frequencies below 50 MHz, antenna size (such as your large AM radio antenna) can become an inconvenience.[8]

At frequencies below 30 MHz, signals bounce off the ionosphere, thus allowing terrestrial signals to transmit thousands of miles. The U.S. government broadcasting service, Voice of America, takes advantage of these low frequencies to transmit thousands of miles into countries with unfriendly regimes.

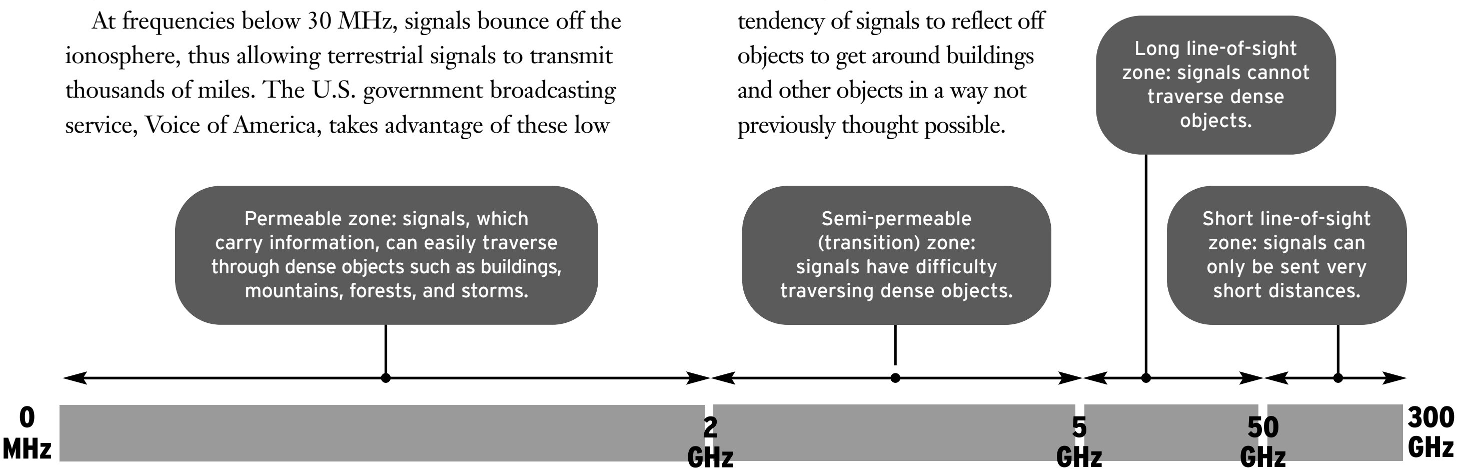
At frequencies above 30 MHz, signals need a higher tower to transmit long distances terrestrially. These permeable signals may be able to penetrate foliage, weather, and buildings, but they cannot penetrate the solid earth. Since the surface of the earth is curved, the distance a signal can travel is a direct function of the height of the tower from which it is transmitted.

There are also some oddball frequencies. Atmospheric oxygen, for example, absorbs signals transmitted at around 60 GHz.

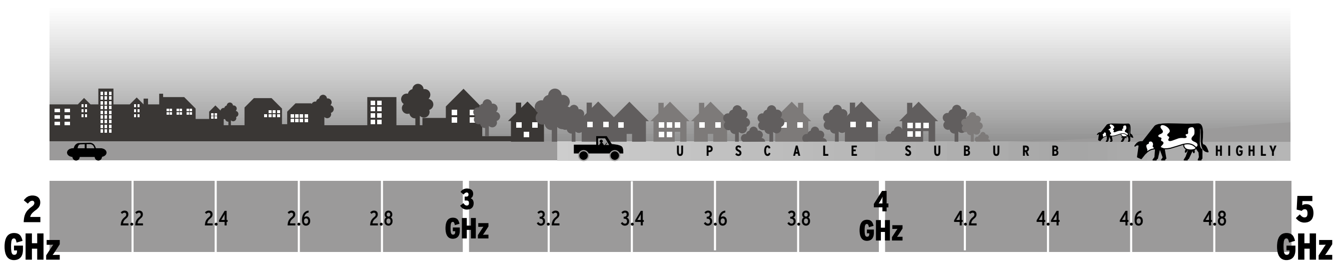
At frequencies above 300 GHz other propagation characteristics come to the fore. Too much human exposure to ultraviolet rays can cause skin cancer (this is why doctors recommend modest exposure to harsh sun). And even relatively short exposure to x-rays can cause cancer and destruction of animal tissue.

Even below 300 GHz, high power signals can heat water (think of a microwave oven heating meat), which is a reason that high frequencies must operate either at lower power levels or with transmitters reasonably distant from humans.[9]

Many weaknesses in propagation characteristics can be addressed via technology. For example, signals attenuate rapidly with distance from the transmitter. The rate at which signals attenuate increases with a signal's frequency. But this can be compensated for by increasing the power levels at which signals are transmitted.[10] Similarly, new smart receivers and transmitters can make much more efficient use of spectrum than dumb equipment. A new smart technology called BLAST uses the tendency of signals to reflect off objects to get around buildings and other objects in a way not previously thought possible.



PROPAGATION CHARACTERISTICS



REAL ESTATE ANALOGY

Valuing Spectrum: A Real Estate Analogy

It is well understood by every adult American that the value of real estate varies by location. The value of one acre of land on Fifth Avenue in New York City, for example, is worth more than one acre in the middle of the Sahara desert in Africa. Similarly, the value of the same bandwidth of spectrum varies by frequency.[11] This chart uses a real estate analogy to illustrate the general decrease in value from low to high frequencies.

The fact that the public does not understand that 10 MHz of bandwidth at 500 MHz is worth far more than the same 10 MHz of bandwidth at 5 GHz or 50 GHz can have great political value. Just as developers used to sell Florida swampland to gullible Northeasterners who didn't understand what they were buying, spectrum lobbyists and their political allies may have strong incentives to pretend that all spectrum is the same.

For example, in 1995, a broad coalition of interests attacked the television broadcasters for their inefficient use of hundreds of megahertz of spectrum. The broadcasters responded, in part, by arguing that their spectrum was only a tiny fraction of total spectrum and that other services used spectrum even less efficiently.[12] They concluded from this analysis that spectrum for new services should be found elsewhere. What they omitted saying was that a lot of spectrum they recommended for more efficient use was in the spectrum equivalent of the Sahara desert.

More recently, the FCC set up the Spectrum Policy Task Force, which issued a report endorsing both licensed and unlicensed spectrum allocations. However, it intends to allocate the lower frequencies to licensed services and the higher frequencies to unlicensed ones. Nowhere does the report acknowledge that the frequencies allocated to these different services have vastly different economic value.

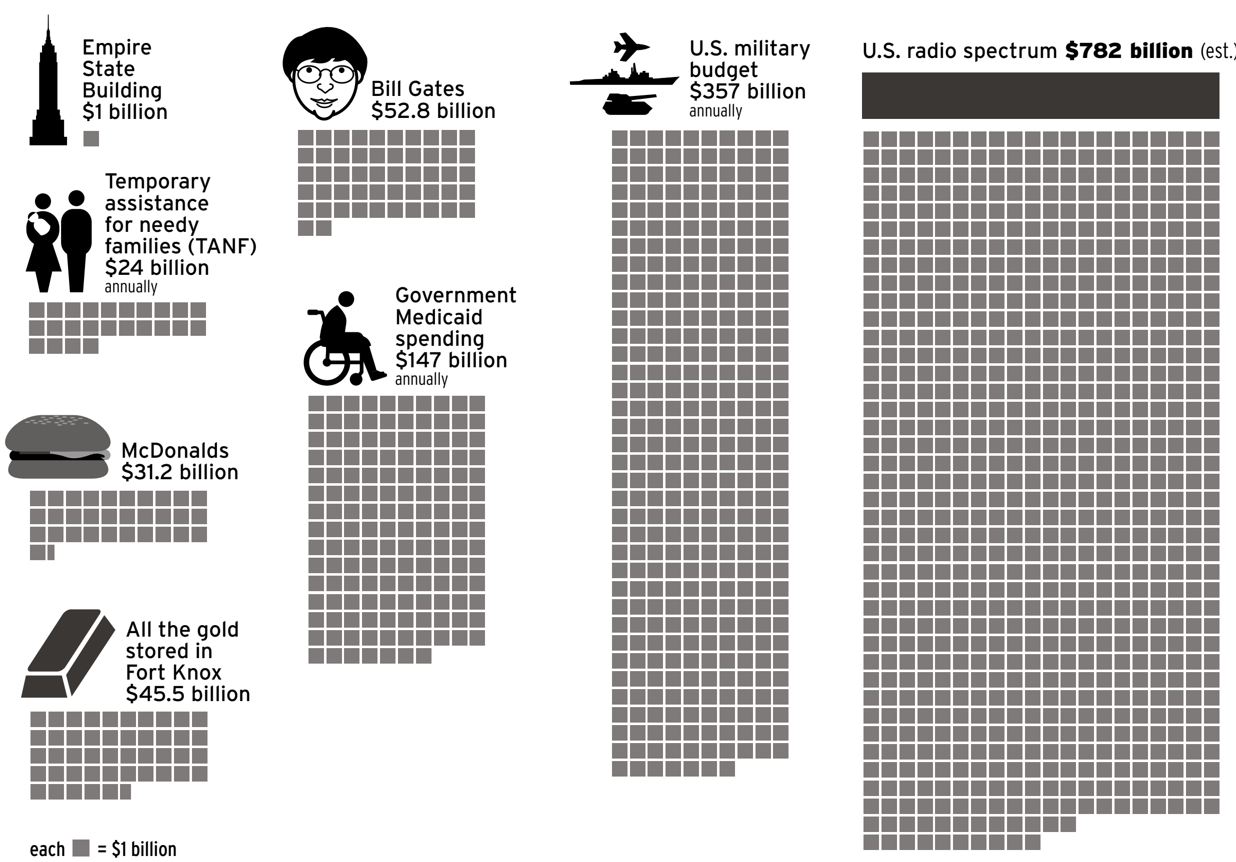
Consistent with the FCC's non-economic allocation arithmetic is a recent statement by FCC Spectrum Policy Executive Committee member Ed Thomas. He crowed to unlicensed advocates that a February 2003 agreement allocating additional unlicensed spectrum at 5.8 GHz "almost doubles what you have." He didn't mention that the reference point for doubling was the far more valuable 2.4 GHz unlicensed band or that the FCC was planning to revoke a small but even more valuable unlicensed band at 1910 MHz.[13]

Closely related to the concept of economic value is the concept of economic use. Just as there is relatively little economic activity in the Sahara dessert, there is relatively little economic activity in the higher frequencies. Frequencies between 100 GHz and 300 GHz are currently rarely used, except for military and scientific purposes. But just as the advent of affordable air conditioning and water transport made the desert location of Phoenix, Arizona into prime real estate, it is likely that the higher frequencies will one day receive much more intensive economic use.

The Spectrum's Worth Compared To Other Things

As we enter the "information age," the means to communicate information becomes a key driver of prosperity. Information may be conveyed through either wires or spectrum. But for any type of highly mobile information service, wired communication may be a poor substitute. For example, you cannot make a wired telephone call while driving your car. Similarly, it may be far cheaper to use a cordless phone than to wire dozens of outlets wherever you might wish to talk in your house. Lack of close substitutes makes spectrum extremely valuable.

In order to comprehend the true magnitude of the radio spectrum's worth, it is useful to compare its value to other financial resources. At an estimated $771 billion, spectrum is worth more than the Empire State Building ($1 billion),[14] McDonalds ($31.2 billion),[15] all the gold in Fort Knox ($45.5 billion),[16] Bill Gates ($52.8 billion),[17] the annual amount the federal government spends on Temporary Assistance to Needy Families ($24 billion),[18] the annual amount it spends on Medicaid ($147 billion), and the annual amount it spends on National Defense ($357 billion).[19] Indeed, the value of the spectrum is worth more than all these things combined. In the next section, we explain how the $771 billion figure was derived and why it is discounted from the $4.5 trillion figure that would seem to be implied by recent auction values. All values are as of December 31, 2001.

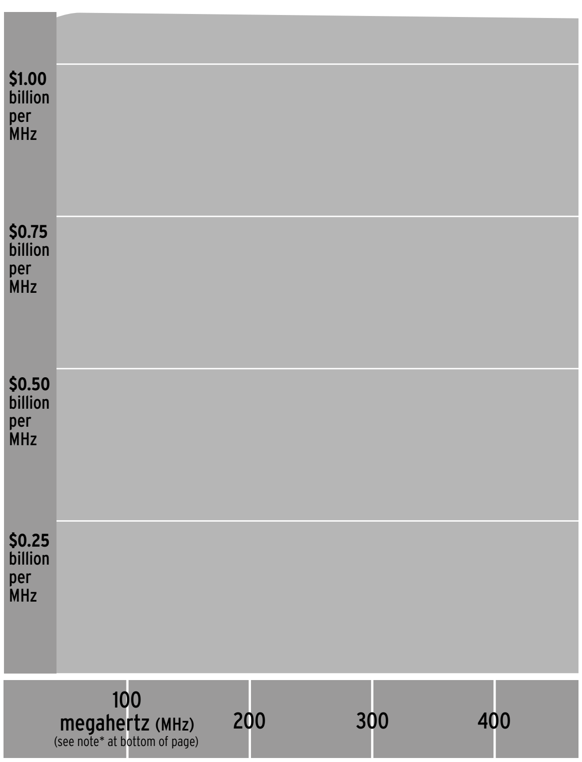


The Value of the Airwaves

Types of Valuation

Spectrum can be valued a number of different ways, depending on the purpose of the valuation. Here we describe four valuation concepts:

- **Current use value.** Licensee receives no new spectrum flexibility. The bundle of rights in a license to use spectrum does not change.
- **Marginal flexibility value.** Licensee, but no one else, is granted complete spectrum flexibility; that is, a single licensee, but none of its potential competitors, wins the right to use assigned spectrum any way it chooses.
- **Universal flexibility value**. Licensee is granted complete spectrum flexibility, but potential competitors do as well.
- **Partial flexibility value.** A subset of licensees is granted complete spectrum flexibility.



THE AXES OF THE SPECTRUM VALUATION GRAPH: VALUE ACROSS FREQUENCY

As an analogy, think of property zoning near a prime beachfront. Currently, the zoning restricts real estate to residential, single-family dwellings on a minimum of five-acre lots. In our hypothetical community, there are 1,000 residential lots, each five acres in size. All the lot owners want to be upgraded to commercial zoning so they can build five star hotels. With current use value, no lot owners can build hotels. With marginal flexibility value, only one lot owner gets rights to build a hotel. With universal flexibility value, all lot owners get rights to build a hotel. Obviously, the flexibility to build a hotel is more valuable if everyone else doesn't also have that right. Partial flexibility value is the intermediate case, where, say, 100 of the 1,000 lot owners get flexibility.

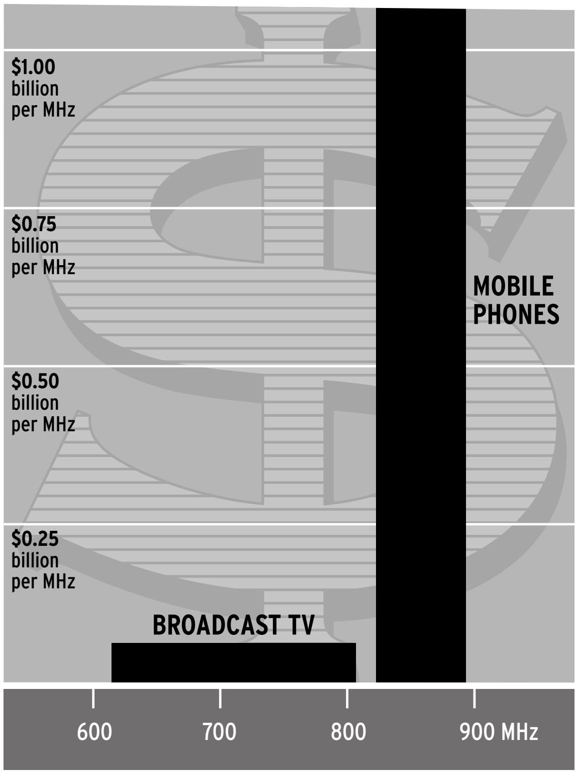
The Valuation Unit ($/ MHz-pop)

The value of spectrum can be broken down into unit prices, the most widely used one of which is dollars per megahertz per person ($/MHz-pop). The unit is defined by two parameters: bandwidth (MHz) and population coverage (pop). Larger bandwidth increases value because it increases the information carrying capacity of a license. Population coverage refers to the number of people—including potential customers—living in the geographic area designated by a spectrum license. The right to use spectrum in highly populated areas is usually much more valuable than the right to use it in sparsely populated regions. If a 1 MHz band of spectrum sells for $1/person, then its value is $280 million if the band covers all 280 million people in the United States.

1) Current Use Values

Spectrum has many commercial uses, and the value of the spectrum in these uses varies considerably. We calculated the value of the spectrum in a handful of different commercial uses, focusing on the economically most important ones. The sum of these values (see Table 1) is $301 billion.

When available, appropriate data from relevant FCC auctions was used to derive the value of spectrum to firms. Some auction data is unsuitable. For some important uses such as TV broadcasting, there have not been useful spectrum auctions. For these uses, we have tried to find sales of firms that have licenses from which spectrum license values can be inferred. Some other end-uses are of little value relative to these, and we have not tried to evaluate them since their values would not affect our total significantly. The Table of Current Use Values



LOW AND HIGH CURRENT USE VALUES

gives a breakdown of the licensed uses with significant value that we have estimated.

We derived the values in the Table of Current Use Values from several sources. First, the FCC has auctioned spectrum. Prices from auctions can be extremely useful information for valuations; however, they must be used with care. There are a variety of reasons why an auction price may not provide a good indication of the value of the spectrum, including those outlined in the next section, "Marginal Flexibility Values."

Mobile Communications. We used Auction 35, the C and F block re-auction, to value spectrum used for Broadband PCS services. In that auction, which ended in January 2001, the winning bids totaled more than $16 billion and averaged $4.18/MHz-pop. None of the concerns described in the next section, "Marginal Flexibility Values," and Appendix A, "Rejected Auction Values with Reasons," applies. Hence, the value of $4.18/MHz-pop is a good estimate of the value to the marginal firm of this spectrum for mobile communications. The actual award of licenses was held up by a lawsuit, but the winning bidders fought hard through the end of 2001 to have their bids honored. Thus, the $4.18/MHz-pop is an

Table 1. Current Use Values

Application	Frequencies [a]	Total MHz [b]	Value MHz-pop	Total Value
Mobile Communications				
Cellular	824-891.5 MHz	50	$4.18	$59.50B
Broadband PCS	1850-1975 MHz	120	$4.18	$142.80B
Other	806-940 MHz	15	$4.18	$17.85B
Broadcasting				
VHF & UHF TV	54-806 MHz	402	$0.233	$26.19B
Radio	0-108 MHz	21	$8.19	$48.16B
Satellite TV	12.2-17.5 GHz	900	$0.021	$5.34B
Satellite Radio	2320-2345 MHz	25	$0.040	$0.28B
Fixed Communications				
LMDS	27.5-31.3 GHz	1300	$0.0024	$0.87B
39 GHz	38.6-40 GHz	1400	$0.0015	$0.59B
News Gathering	1990-2025 MHz	35	$0.0204	$0.20B
		Grand Total		**$301.78B**

Note:
a. This indicates the range of frequencies in which this service is located. The entire spectrum range is not necessarily used for the indicated purpose.
b. This column shows the total amount of spectrum used for the indicated purpose.

appropriate, perhaps even slightly conservative, market value as of our evaluation date of December 31, 2001. Since there is very little difference between the services offered or the costs of offering them on other Broadband PCS frequencies, we use this value for all 120 MHz of Broadband PCS frequencies.

Mobile communications services are also offered on 50 MHz of cellular frequencies and 15 MHz of other frequencies. Again, the spectrum used for these services can offer essentially the same capabilities at approximately the same cost, so we have also used the unit price of $4.18/MHz-pop to value these bands.

Broadcast Television. There have not been useful auctions for determining market value of spectrum for conventional radio and television broadcasting services.[20] Thus, the evaluation of the use value of this spectrum needs to come from a different source, the best of which are sales of stations. In particular, we have used much of the methodology employed by the FCC's Chief of the Office of Plans and Policy, Dr. Robert M. Pepper, in answering an inquiry from Senator Joseph I. Lieberman.[21] Using this methodology, we started with the 2001 advertising revenue of the broadcast television industry, $35,930,310,400.[22] Dr. Pepper reports that the industry average operating cash flow (OCF) is 30% of total revenues and that station values are eight to ten times OCF. We used the 30% factor and a factor of nine to get a total value of TV stations as 2.7 times annual advertising revenues [9 x 30%]. We estimated the value of the physical assets of TV stations at 10% of total value, leaving a factor of 2.43 times annual advertising revenues as the value of the broadcast rights [2.7 x 90%]. (The second Dr. Pepper letter indicates that the physical assets in the WNYC sale were about 5% of the total value, but a New York license is probably worth more relative to the physical assets needed to use it, so we used 10% for a national average.)

At this point, however, we deviated from Dr. Pepper's methodology. Most of the value of the broadcast rights no longer comes from over-the-air broadcasting. Many of the viewers for which advertisers are paying receive their signals via cable or satellite feeds. About 68% of U.S. television households pay for cable TV, and cable operators are required by law to carry broadcast signals in the area they serve. This "must-carry" rule is extremely valuable to broadcasters. About 20% of U.S. television households pay for satellite TV and 65% of them pay for satellite access to local broadcast signals. At present, 87% of the households in the U.S. are capable of receiving TV signals from cable or satellite feeds.[23] However, not all of the viewing in such households is on these feeds. While some of the viewing in connected households may occur via broadcast signals, the households are paying approximately $500 per year for cable or satellite feeds, and in about 93% of the households these feeds have all of the broadcast signals. Thus, it seems safe to assume that most of their viewing is on the paid feeds. An additional consideration is that the over-the-air broadcasting provides a backup for cable failures. However, offsetting this is the fact that households without subscription TV tend to be poorer and worth less to advertisers than those with subscription television. Taking all of this into account, we estimate that currently 70% of the value of a TV station is due to non-broadcast signals and only 30% is due to the over-the-air broadcasting use of the spectrum. Thus, we arrived at a value of 72.9% of annual advertising revenues, or $26.19 billion, for the spectrum use [2.43 x 30%]. Using a U.S. population of 280 million and 402 MHz of consumer-delivery spectrum, this works out to $0.233 per MHz-pop.

Electronic Newsgathering. Television broadcasters not only have 402 MHz of consumer-delivery spectrum for broadcasting, they have much more "auxiliary" spectrum, including 120 MHz of spectrum between 1990 and 2110 MHz for electronic newsgathering (ENG), primarily used for transmitting remote news coverage to the studio. Regardless of claims of full-occupancy, this spectrum is not used in the most efficient manner. The FCC has recently decided that television broadcasters must (gradually) use the spectrum more efficiently and give up 35 MHz of this ENG spectrum. In comments filed on behalf of the National Association of Broadcasters in response to FCC docket 95-18, the equipment needed to accompany the reduction of ENG spectrum from 120 MHz to 85 MHz would "be of sufficient quality to replicate the present analog ENG transmissions."[24] According to comments filed by the Society of Broadcast Engineers, the cost of this is about $200 million, for a valuation of $.020/MHz-pop for the 35 MHz vacated.[25] (The remaining 85 MHz is much harder to evaluate and it is not clear what the substitute for it is. Furthermore, the spectrum is shared with the U.S. civil space program, and there is concern that radically more intensive use would adversely impact it.[26] Thus, we have not valued that spectrum.)

ON THE SPECTRUM'S WORTH

"[Spectrum is] the most valuable natural resource of the information age."

WILLIAM SAFIRE, *THE NEW YORK TIMES*[32]

"The radio spectrum is to the information age what oil and steel were to the industrial age."

SENATOR PRESSLER, FORMER CHAIR, SENATE COMMERCE COMMITTEE[33]

"Although the radio spectrum spans the range from 3 kilohertz to 300 gigahertz, 90 percent of its use is concentrated in the 1 percent of frequencies that lie below 3.1 gigahertz, because these frequencies have properties that make this portion of the spectrum well suited for many important wireless technologies."

U.S. GENERAL ACCOUNTING OFFICE REPORT, JANUARY 2003[34]

Radio Broadcasting. We employed a similar methodology as that of television broadcasting for AM and FM radio broadcasting. The latest advertising revenue figure is $19,819,000,000 for the year 2000.[27] We used the same factor of 2.43 times annual advertising revenue as we did for broadcast TV, but we did not reduce this multiple since there are no must-carry rights and the vast bulk of radio listening is done through over-the-air broadcasting. With less than 21 MHz of consumer-delivery spectrum and an industry value of $48.16 billion, this works out to $8.19/MHz-pop.

Companies are actively trying to get spectrum for mobile communications uses, but there does not appear to be comparable pressure for getting spectrum and converting it to conventional radio broadcasting stations. Instinctively, one may question whether it is reasonable to value the spectrum for radio broadcasting at almost twice the unit price as that for mobile communications. The answer is "yes." The radio broadcasting value depends upon the existence of a large number of receivers that pick up certain frequencies, namely 88 to 108 MHz for FM and 535 to 1705 kHz for AM; it is commonly estimated that there are, on average, more than five radios per U.S. household not including car radios.[28] Anyone converting another frequency band to be used for radio broadcasting could not expect to earn as much money as current radio broadcasting stations do until many new radios – capable of receiving the new frequency – were sold over many years. Additionally, radio is unmatched in terms of penetration, reaching 78% of consumers every day and 96% every week.[29] The situation of radio's high valuation is quite unusual.

Satellite Radio. In 1997, the FCC auctioned two licenses covering 25 MHz of spectrum for national satellite radio. The license winners are just starting up these services. (One of the licensees, XM Radio, just began broadcasting on November 12, 2001.)[30] It is too soon (and thus there is no available data) to evaluate these services as mature businesses, but based upon the amount for which the licenses sold, and making the conservative assumption that the auction winners required a 10% per year return on their investment, we estimate the current value of the licenses to be $0.28 billion, or $0.040/MHz-pop.

Satellite Television. The FCC has also auctioned licenses for 900 MHz of high frequency spectrum to be used for satellite television. The 900 MHz of spectrum supports the use of 96 satellite transponders that cover the entire United States and 160 less-valuable satellite transponders that only cover part of it. Twenty-four of the former and 28 of the latter were auctioned in January 1996. The 24 full-coverage transponders sold for $682 million. Thus, at that unit price, the 96 full-coverage transponders were worth $2.728 billion. The 28 partial-coverage transponders sold for $50.3 million. Thus, the 160 partial-coverage transponders were worth as much as $299 million. In total, the transponders were worth up to $3.027 billion.[31] Assuming 10% appreciation per year since 1996, the transponders were worth $5.34 billion as of December

31, 2001.[35] Since the transponders use 900 MHz of spectrum, the unit price is $0.021/MHz-pop.

The two large bands of high frequency spectrum for fixed communications services shown in the Table of Current Use Values have both been auctioned. In both cases, the winners are moving ahead with plans but do not yet have operating businesses. Therefore, just as with satellite radio, we have based the valuation on the auction price escalated at 10% per year to derive the valuations shown in the Table of Current Use Values.

There are other bands for which the value is clearly zero or near zero, but we have not included them in the Table of Current Use Values since they will not affect the total value we are calculating. An example of this is the spectrum allocated to failed non-geostationary mobile satellite phone services.

2) Marginal Flexibility Values

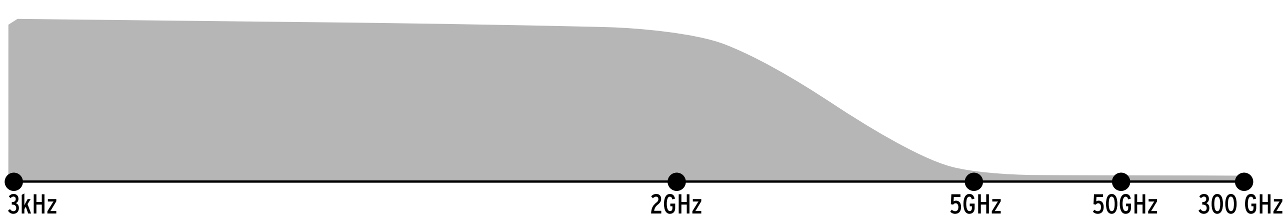
The Marginal Flexibility Value Curve represents the value of radio spectrum in its highest valued use today. Specifically, it maps the value of a marginal amount of radio spectrum if it were allowed to be utilized in its highest valued possible use. As a result, the curve is intended to be a reference point for comparing the value of radio spectrum in its current use; the curve is not intended to value the total radio spectrum.[36]

Shape of the Curve. The general shape of the Marginal Flexibility Value Curve is driven by a combination of physical and economic factors. The most notable feature is the steep drop in value that occurs in the 3 GHz to 5 GHz range. For frequencies below that range, radio spectrum is most suitable for mobile uses, such as wireless phones and radios in cars, and non-line-of-sight applications like terrestrial television broadcasting and wireless home computer networking.

Mobile uses tend to be more valuable for two main reasons: First, the flexibility provided by mobility is a highly desired feature; second, in most cases, no substitutes for the radio spectrum exist to provide the particular service. Consider, for example, communications with and among ships. When two ships are within the line-of-sight of each other, it is possible to use semaphore or light flashes to transmit Morse code. When beyond the line-of-sight of each other, however, radio communications is the only practicable means of communication between the two ships. Similarly, with other untethered communications, radio is usually the only option. The limited supply of physically desirable radio spectrum at the lower frequencies combined with the economic desirability of mobility make the unit value of the lower frequencies comparatively higher.

In contrast to the lower frequencies, the higher radio frequencies are well suited for point-to-point communications. For most applications this requires both the transmitter and receiver to be within the line-of-sight of each other. Although point-to-point communications are valuable, the upper frequencies of radio spectrum are relatively less valuable for two reasons: First, there is a greater quantity of frequencies available above the 3 GHz to 5 GHz threshold than below it; second, non-radio-based substitutes, such as fiber optic cables, are often an economical substitute for radio-based communications. As reflected in the noticeably lower height of the curve, these factors help make the higher frequencies relatively less valuable than the lower frequencies.

At its core, this curve represents a marginal valuation of radio spectrum. It is intended to trace out the highest valuations for spectrum under several restrictive assumptions. Foremost, the analysis only looks at marginal sales of spectrum. Underpinning the analysis is the assumption that, overall, radio spectrum tomorrow will remain essentially as scarce as it is today. Among other things, this implies that all other uses of the spectrum stay effectively unchanged. A further assumption is that each bit of spectrum—and that bit alone—will be allowed to be used in its highest possible valued use. That is, the new use of the



MARGINAL FLEXIBILITY VALUES

ON THE EQUITY AND EFFICIENCY OF SPECTRUM FLEXIBILITY

"It's like giving Yellowstone National Park to timber companies."

WILLIAM SAFIRE, *THE NEW YORK TIMES*[45]

"[T]he greatest taxpayer ripoff of the century."

ADAM THIERER, CATO INSTITUTE[46]

"In the current environment, spectrum allocation decisions often do not effectively push spectrum to its highest-valued and most efficient use."

THOMAS J. SUGRUE, CHIEF OF WIRELESS TELECOMMUNICATIONS BUREAU, FCC[47]

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marginal spectrum is unrestricted, without onerous interference restrictions or incumbents to be cleared, while the uses of other spectrum remain unchanged.

Considerations for Evaluating Licenses. Spectrum license auctions do not sell full property rights to spectrum. In fact, no property right is absolute; they all have strings attached. At the very least, the government can use powers of eminent domain to commandeer property. Less drastic examples are zoning regulations on land use and speed limits on highways. These restrictions generally correct for some externality. For example, residential-only zoning is a shortcut to preventing the nuisance of commercial traffic or industrial pollution in a residential neighborhood. (It is a shortcut because these same problems could be solved through negotiations, given complete property rights and no transactions costs.)[37]

Spectrum auctions sell licenses to operate a service on given spectrum. Traditionally, spectrum licenses have been more like a business license than a property right. For example, although a television station license assigns a particular frequency in a specified geographic area to the licensee, it is really much more like a license to operate a broadcast television station than a deed to own a slice of the radio spectrum.

Restrictions on what a licensee can do affect valuations in competing ways. For example, a television broadcaster is not free to abandon the television broadcasting business and become a mobile telephone operator (a relatively more valuable use) with the frequencies assigned in its license. At the same time, however, restrictions on other licensees mean a television broadcaster does not have to fear an influx of new entrants into its business, which would tend to reduce profits and hence the value of its license.

Radio spectrum is the resource that is common to the FCC spectrum licenses. To value that resource, and not the value of the other set of rights associated with a particular license, we need to back-out the resource value from the license value. For current spectrum resource values, the best way to do this is to use a market-determined value of a license where the other restrictions on use are not binding constraints—that is, where the underlying spectrum resource would continue to be used as intended in the license if those license restrictions were lifted. It is also assumed that the value of the intended use in the auctioned license is not unduly inflated because of past regulations.[38]

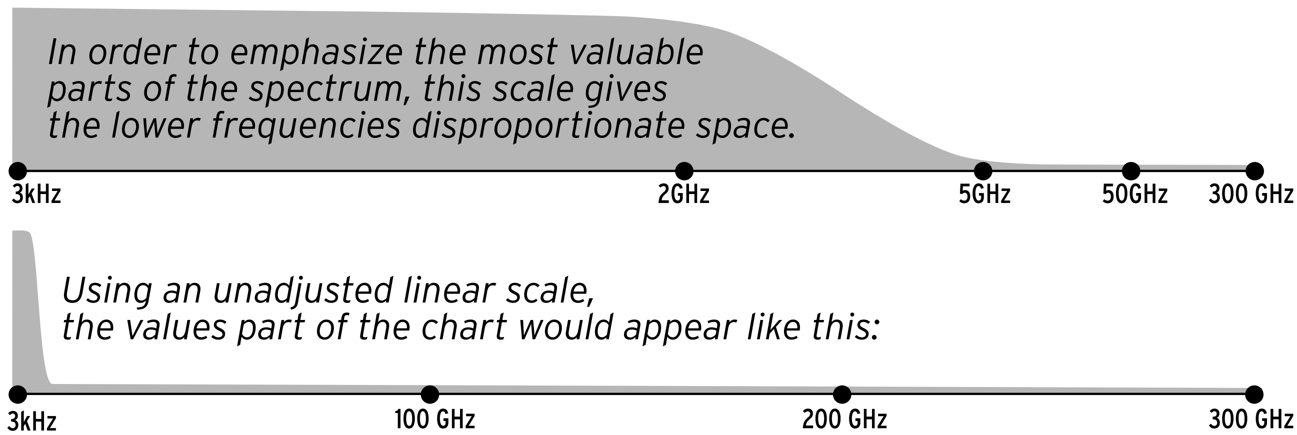
Auction Data. Three auctions were used as anchors for the Marginal Market Value Curve:

- C and F Block Broadband PCS License Auction (Auction #35)[39]
- Local Multipoint Distribution System (Auction #17)[40]
- 39 GHz Auction (Auction #30)[41]

Appendix A lists the remaining FCC license auctions and the reasons they were rejected as unrepresentative of the underlying spectrum value.

There are many reasons to reject a specific auction as unrepresentative of underlying spectrum values, including:

- Incumbents in band[42]
- Restrictive interference criterion[43]
- License bandwidth is particularly small[44]



LINEAR VS. ZONED SCALE

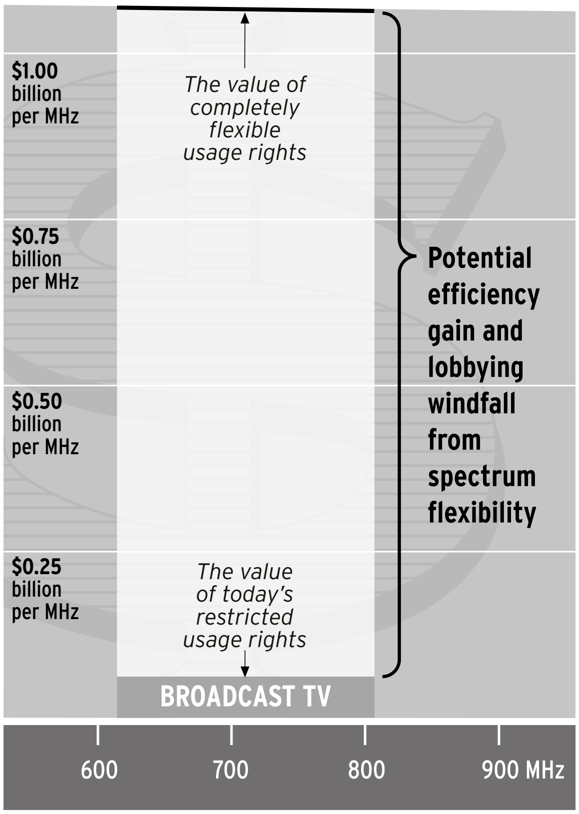
- Licensed spectrum only covers a portion of the country[48]
- Valuation superceded by more recent auction[49]
- Spectrum block too small for spectrum band[50]
- Restrictions on use[51]
- Post auction use did not meet expectations[52]

Validity of the Marginal Flexibility Curve. The Marginal Value Curve is meant only to describe, in a generic manner, the highest valued uses radio spectrum could be put as of December 31, 2001, the cutoff point for data used in this analysis.[53] The method used to generate this curve is interpolation.

To interpolate a curve, it is necessary to begin by picking several data points. The valuation points used for the curve were selected from FCC auctions as likely to be representative of underlying generic spectrum values. Auction prices, and the underlying spectrum values, can be quite fickle. For example, depending upon the auction date, Broadband PCS auction valuations have varied from approximately $0.26/MHz-pop for the original F block to $4.18/MHz-pop for the C and F block re-auction. Nevertheless, it is better to anchor the marginal valuation curve in real, observed market prices of spectrum than to try to adjust those prices for current, and probably transient, trends.

Using different anchor points, the interpolated curve would be shifted up or down. Perhaps the marginal value of prime spectrum in the 2 GHz band is $2/MHz-pop or maybe $6/MHz-pop. Arguments could be made for both. However, anchoring it in carefully selected auction valuations is a sound approach. Importantly, the overall shape of the curve would not change significantly with different starting points for the interpolation. As discussed above, the shape is driven by economic and physical properties of the radio spectrum that are much broader than the specific valuations manifest in an auction or two.

Linear vs. Zoned Scale. It is important to keep in mind that the visual scale is not linear. To emphasize the most valuable and most intensively used parts of the spectrum, the lower frequencies are given space disproportionate to their bandwidth. Using a linear scale would shift the valuable frequencies so far to the left as to be almost invisible. Consequently, one should not read too much into the slope of the curve. For example, if the semi-permeable zone had the same scale as the permeable zone, the slope of its curve would be one-third its present value.



MARGINAL VS. CURRENT USE VALUE

Equity and Efficiency Implications

The area represented by the discrepancy between current use and marginal flexible use values has an equity and efficiency interpretation:

- **Efficiency.** The efficiency loss from not allowing this spectrum to be used for services most highly valued by consumers.
- **Equity.** The windfall an incumbent spectrum licensee could receive if granted flexibility to use it for any purpose or to sell it (i.e., full property rights). Alternately, the government could charge market rates for use of this public asset, with the receipts going into the U.S. Treasury rather than the pockets of spectrum incumbents (i.e., a public auction or property leasing arrangement).

To illustrate these concepts, consider TV channel 14. There are 67 broadcast TV channels, and let's assume channel 14 is worth 1/67 of the total value of all the 67 TV channels. Today, the government restricts the use of the 6 MHz called channel 14 to primarily broadcast TV use. The market value of this inflexibly licensed spectrum is $390 million.

If the government allows the same 6 MHz to be put to its most highly valued use (e.g., cellular telephone service), its market value jumps to $7.2 billion. The difference ($6.8 billion) is the potential value of spectrum flexibility on channel 14. The efficiency consideration is that the market values the 6 MHz of channel 14 spectrum more for mobile telephone and Internet service (about $6.8 billion more) than terrestrial over-the-air broadcast TV service. The equity consideration is whether the public or the incumbent broadcast TV license holders should get the windfall from efficient spectrum use. Of course, if all spectrum users, not just channel 14 TV broadcasters, were granted flexibility, the greater supply of spectrum would reduce the market value of channel 14 flexibility.

Efficiency Considerations. The current spectrum management system does not allow spectrum to be used for its highest valued uses. Consequently, spectrum allocated to services in high demand, such as cellular telephony, is very valuable on a unit price ($/MHz-pop) basis and spectrum allocated to services in relatively less demand, such as broadcast television, have low unit prices. As demand for spectrum-based services continues to evolve, these imbalances change over time. For example, as demand for mobile phones grew faster than expected in the later 1990s, the value of PCS spectrum grew from $0.52/MHz-pop in 1995 (as reflected in the A & B block auction) to $4.18/MHz-pop in 2001 (as reflected in the C block re-auction).

The marginal valuation curve on the spectrum chart describes how the value of a band of spectrum changes with its physical characteristics, *if it was the most valuable band of spectrum*. That is, under the current system of spectrum management with all of its misallocations, if any single band of spectrum was allowed to migrate to its highest valued uses, it would be worth the amount indicated by the marginal valuation curve. This is in contrast to the various current valuations of specific bands of spectrum, which measure the bands' current value in the overall context of the current spectrum management system.

The difference between the current value of a band of spectrum and its marginal valuation under flexibility is a measure of value unrealized for that band. To be

"While today's massive underutilization of spectrum suggests that markets and new technology may increase available spectrum by orders of magnitude, we have no doubt that clever engineers and aggressive marketers will find ways to fill that spectrum with new and useful gadgets that we all must have."

GERALD FAULHABER, PROFESSOR, WHARTON SCHOOL[56]

clear, it represents only the unrealized value for a specific band, holding the utilization of the rest of the spectrum constant.

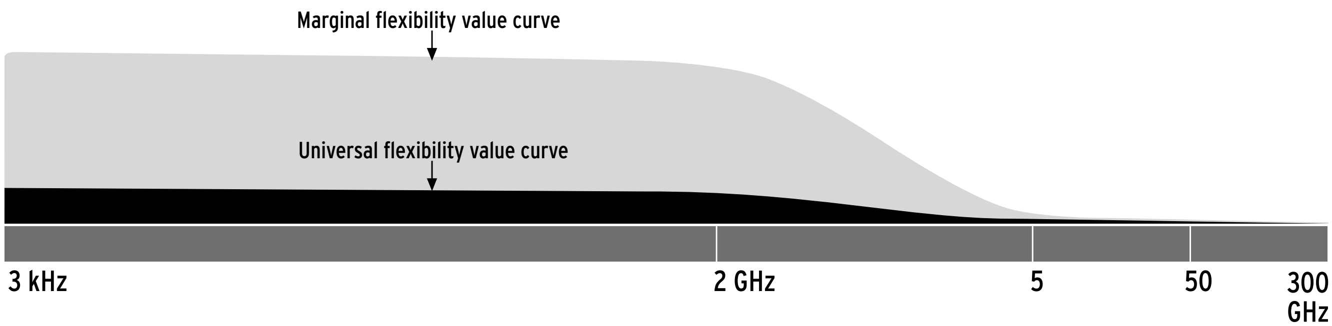
Equity Considerations. Examination of the value of individual spectrum bands dedicated to particular uses also makes clear the huge financial gains available to companies that can arrange to be *given* the right to change the usage for which they are licensed. For example, consider the holders of licenses for the spectrum between 2150 and 2160 MHz. This relatively small 10 MHz band of spectrum was licensed for fixed communication services that are not particularly valuable at present. Since the spectrum is located near valuable bands used for mobile communications, if the holders of those licenses were granted spectrum flexibility (without others receiving flexibility), they could then sell the licenses for mobile communications. At this writing, the FCC[54] is considering permitting mobile communications in the 2150-2160 MHz band. Based upon the value of such usage mentioned above, this would increase the value of the licenses by more than $11 billion. This financial incentive puts extreme pressure on government decision-making, as the potential gains from successful lobbying are enormous.

It is hard to estimate the total gain over the long term that is available from lobbying. Our Delphi study suggests that over the next decade alone, a gain of $318 billion can be realized by more efficient spectrum use. Successful lobbying might capture all of this gain. However, over a longer period, given the huge growth in demand for radio communications, there are even greater potential gains. If the television broadcasting industry could, over a sufficiently long period of time, drive the value of their 402 MHz of consumer-delivery broadcast spectrum up to the $4.18/MHz-pop of the telecommunications industry, that gain alone would be worth $444 billion.

While there are obvious efficiency benefits from relaxing the restrictions on the use of spectrum, there are two important cautions. First, it is inefficient for the government to fail to collect the value of the gain that would come from granting flexibility. To the extent that it fails to do so, it will have to raise an equivalent amount of money from taxes. Throughout economic literature, it is well documented that there are significant inefficiencies from raising money from taxes. A conservative estimate is that for every three dollars in revenue forgone (and, therefore in additional taxes raised) there is one dollar of lost productivity.[55] Thus, if during the next decade the government were to relax the usage of spectrum as envisioned in the Delphi study and not collect any of that value of $318 billion, it would cost the country an additional $106 billion in lost economic activity. Secondly, there is an equity concern. The present licensees have limited rights. It is impossible to justify giving them a windfall during the next decade of $318 billion.

3) Hypothetical (i.e., Universal) Flexibility Values

A notable feature of the bars representing the value of select bands of spectrum in their current uses is the variability of those values. Some bands have high unit values, likely indicating that in a less constrained spectrum management environment more licensees would shift their spectrum to these more profitable uses. Other bands have very low unit prices, indicating that, if free to do so, spectrum would migrate out of those uses to higher valued uses. Currently, there is no single average or unit price for spectrum. If the process of spectrum moving from lower valued uses to higher valued uses was allowed to play out, a new set of bars indicating valuations for current uses would all be roughly the same height. (The unit prices would vary for some reasons including the position



MARGINAL VS. UNIVERSAL FLEXIBILITY VALUES

of the band on the radio spectrum.) That is, market forces would tend to equalize the unit price of spectrum.

Where that hypothetical unit or average price of spectrum, and by extension the overall value of the radio spectrum, would settle out is unknowable at this time. Large changes in allocations and services offered create so much uncertainty that changes in valuation would be impossible to forecast with any degree of accuracy. Nevertheless, we can describe the forces at work that would move spectrum valuations from their current levels to a level reflecting flexibility.

Allowing spectrum to migrate to higher valued uses has the same effect as increasing the supply of spectrum under the current management system. If a high demand service implicitly values spectrum at $2/MHz-pop and another use values it at $0.50/MHz-pop, then for $2 (the amount the high value user values one unit of spectrum) the high value user can purchase up to 4 units of spectrum from the low value user. (The exact terms of trade between the low and high valued users of spectrum will depend on the relative strength of each party in negotiations.) This supply effect is equivalent to pushing out to the right the supply curve in a simplified supply and demand representation. Holding all other factors (like demand) constant, an increased supply curve will lead to a larger quantity of the good (in this case effective spectrum) at lower prices.

Allowing spectrum to migrate to new uses will also likely usher in many new spectrum-based services that are not available today. Demands for these new services will create new derived demands for spectrum. This demand effect is equivalent to pushing out to the right the demand curve in a simplified supply and demand representation. Holding all other factors (like supply) constant, an increased demand curve will lead to a larger quantity of the good (in this case effective spectrum) at higher prices.

Whether the average value of spectrum will increase or decrease (or stay about the same) after flexibility is introduced into the system of spectrum management will depend on the effective supply and demand increases. Both the usable supply of and demand for spectrum have increased tremendously over the last century (See "Demand for Spectrum Is Surging" and "Have We Reached the Spectrum Frontier?"). The belief that after liberalization demand will grow faster than the effective increases in supply implies that the post-reform average values of spectrum will increase. Likewise, belief that liberalization will cause effective supply to grow relatively faster than demand implies that the post-reform average values of spectrum will decrease. A third view—advocated by some economists who would prefer to ignore equity considerations in their analyses—is that effective supply and demand will both grow as a result of spectrum liberalization and that the overall average value of spectrum will remain basically unchanged.

4) Partial Flexibility Value

In practice, total liberalization is not likely. It will be very difficult to bring large amounts of government-controlled spectrum under market forces, including spectrum used for public safety and national defense. Consequently, we have focused on a subset of spectrum that is already under private control where increased flexibility in use is at least a possibility. The amount of spectrum analyzed in this section is substantially less than the total amount of spectrum, but considerably more than amounts considered in other spectrum reform proposals.[57]

Spectrum Bands Not Valued. Part of the radio spectrum in the United States is reserved for use by the federal government. By law, the National Telecommunications and Information Administration (NTIA) in the Department of Commerce administers this part of the radio spectrum for the executive branch of the federal government. The Federal Communications Commission (FCC) administers the remaining U.S. spectrum for non-federal users. The FCC reserves part of the spectrum it administers for local and state governments. It licenses the rest to private organizations for broadcasting, communications, and other services. We are not valuing spectrum controlled by the federal government for defense, air traffic control, domestic security, or any other use. Nor are we considering spectrum used by state and local governments or otherwise set aside by the FCC for public safety. We are only valuing spectrum identified in the current use value section.

Like stock market prices, the value of spectrum fluctuates. Hence, any valuation has to be made in reference to a particular date. As noted earlier, the date we are using is December 31, 2001. Within the past two years, the value of spectrum has been both higher and lower than it was on that date.

Valuation Components. Our basic approach to estimating the value of commercial spectrum is "divide and conquer." We first divided the value into two parts: current value to licensees and value from unrestricted use. We further divided the value to current licenses by differentiating the value to marginal firms and the additional value to more efficient firms. This valuation exercise is performed on distinct bands of spectrum allocated for different uses. We take advantage of the fact that much of the value to spectrum licensees comes from just a few of the many, many licensed uses of spectrum.[58] It is on these uses that we concentrate. To the extent that we have omitted valuations of other commercial spectrum uses, our value is conservative.

The first part of the value we are estimating, the current value to licensees, is the value of the spectrum to the licensees, including the value to the marginally efficient firm and the value to firms that can make substantially better use of the spectrum than the marginal firm. Our total for this part of the value is $452.67 billion. This value is a conservative estimate of the value of the radio spectrum in that it does not value spectrum used by the state, local, or federal governments, even though they have access to a majority of the airwaves.

FCC licenses are licenses for specific uses of spectrum. Sometimes these are not the most valuable uses. The second part of the value we are estimating, the value of unrestricted use, is the total additional value licensees could achieve over the next decade if they were free to use the spectrum in the most valuable manner (i.e., full flexibility). Our estimate of this additional value to licensees from more efficient use of the spectrum is $318 billion. The sum of these two values is just over $771 billion. Note that we are not including the extra value to consumers of the services offered by licensees. This value is extremely hard to measure, but it may well be several times as large as the value we have measured.

Current Value to Licensees. The total current use value, $301.78 billion, is the value of spectrum to marginal firms. However, most firms holding spectrum earn more than a marginal return on their holding. Therefore, the spectrum is worth more to them and, from it they derive "producer surplus," that is, extra value above the value to the marginal firm. If we assume that, on average, current use values vary smoothly from the marginal firm to firms that are able to earn twice what the marginal firm does on the spectrum, then the producer surplus is half of the marginal value of $301.78 billion, or $150.89 billion. This brings the total value of spectrum to licensees to $452.67 billion.

The Value of Flexible Use. Next, we considered the additional value of spectrum to companies if they could have spectrum to use as they see fit. Lacking verifiable data for this purpose, we turned to expert opinion in what is sometimes called a "Delphi study." Assembling a small panel of leading independent experts in the economics and technology of spectrum use and assuring them of anonymity, we asked the experts to answer a series of questions about how much companies would be willing to pay for various amounts of spectrum in two different ranges (below 3.5 GHz and above it) and what the companies would use it for. We then circulated all of the answers to the panel members (anonymously) and offered panel members the chance to alter their answers based upon the answers or comments of the other panelists. When no one wished to change his answers further, we used answers in the two ranges to fit a demand curve for spectrum by companies. The area under such a curve gives the additional value that companies could gain from additional spectrum. Given the great uncer-

FAMOUS ERRORS IN PREDICTING SUPPLY AND DEMAND

SUPPLY

"[A] few decades hence, energy may be free – just like the unmetered air."

JOHN VON NEUMANN, FERMI AWARD-WINNING AMERICAN SCIENTIST, 1956

"[B]y 1980 all 'power' (electric, atomic, solar) is likely to be virtually costless."

HENRY LUCE, FOUNDER AND PUBLISHER OF *TIME*, *LIFE*, AND *FORTUNE MAGAZINES*, 1956

DEMAND

"I think there is a world market for about five computers."

THOMAS J. WATSON, CHAIRMAN, IBM, 1943

"There is no reason for any individual to have a computer in their home."

KEN OLSON, PRESIDENT, DIGITAL EQUIPMENT CORPORATION, 1977

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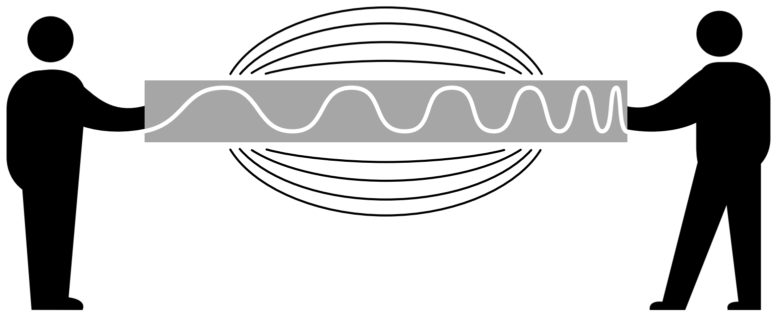
tainty of the overall situation relative to the variation in the answers, we averaged the answers in each range. The result was an additional potential value of $257 billion for spectrum below 3.5 GHz and $61 billion for spectrum above 3.5 GHz for a total of $318 billion of potential value from spectrum flexibility. Given the overall uncertainty of this estimate and the fact that there is a substantial amount of spectrum that is producing little or no value, we did not subtract anything for the value of the spectrum uses that would be given up.

As emphasized in Appendix B, the attached Delphi questionnaire, the questions are limited by the phrase "in the next decade." Thus, these are questions about what is achievable in a reasonable business planning horizon rather than mere speculation about the distant future.

An interesting side-note of the Delphi study was that while the experts disagreed somewhat on the amount of added value that could be achieved in the next decade from additional spectrum, they did not differ significantly about how much spectrum would produce half of the added value that they envisioned, and that amount was not very large. For the spectrum below 3.5 GHz, the opinion of all of the experts was that between about 140 MHz and 180 MHz of additional spectrum would produce half of the total benefit they envisioned. For spectrum above 3.5 GHz, there was a consensus that about 300 MHz would produce half of the envisioned benefit.

When we put back together the separate segments of value we have calculated, we obtain the $771 billion for potential total value to license holders of licenses for completely flexible licenses.[59] This includes the market value of the licenses as of December 31, 2001, the extra value of the licenses to firms that are more than marginally efficient (producer surplus), and the extra value available in the next decade from liberalization of restrictions.

Note that as large as the $771 billion figure is, it does not include consumer surplus. A full cost-benefit analysis would include consumer surplus, but we have not attempted to estimate it for two reasons. First, it is extremely hard to measure. Second, it doesn't shed light onto the motivations of spectrum incumbents, who are motivated by the potential for producer surplus, not consumer surplus. However, no analysis of welfare or spectrum policy would be complete without taking into consideration consumer surplus. Unlicensed spectrum, for example, has huge consumer surplus but possibly no producer surplus. No producer gets a cut when you use spectrum for your cordless phone, garage door opener, or home Wi-Fi network. Nevertheless these services may well provide consumers with great value. Good spectrum policy will need to balance the values that can be achieved with unlicensed spectrum against the benefits of licensed spectrum.



PART II

Back Side of the Poster

Who Owns the Airwaves?

The Communications Act of 1934 is very clear: the airwaves belong to the public.

> "It is the purpose of this Act, among other things, to maintain the control of the United States over all the channels of interstate and foreign radio transmissions; and to provide for the use of such channels, but not the ownership thereof, by persons for limited periods of time, under licenses granted by Federal authority, and no such license shall be construed to create any right, beyond the terms, conditions, and periods of the license."[60]

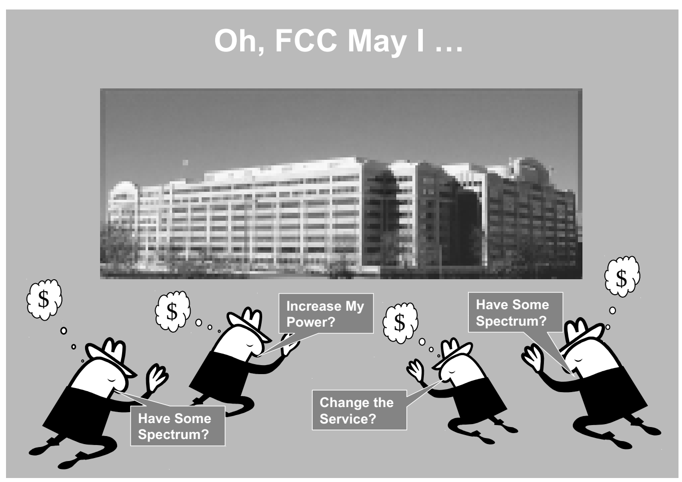
In practice, however, the government has never terminated an industry's spectrum allocation without compensation. Even in the rare circumstance when it has auctioned spectrum, it has found a way to compensate incumbent license holders. For example, when the government reallocated frequencies for auction to cellular phone companies during the 1990s, it relocated incumbent microwave operators to different bands—and encouraged auction winners to compensate incumbents for the costs associated with moving to the new band.

The government has, on occasion, reclaimed an individual license when a licensee has demonstrated gross failure to fulfill its license terms. But in recent decades, even such minimal repossessions have all but disappeared.

Politics is probably the simplest explanation why Congress and the FCC don't enforce the Communications Act. Licensees tend to fear that if the Communications Act were enforced with one licensee, it could be enforced with all, and thus react with furious opposition whenever a political leader threatens to enforce it. Political leaders know to expect this opposition, and they also know the general public won't care one way or the other. The political calculus is thus clear: the low risk strategy is to ignore the Communications Act.

Who Manages Access to the Airwaves?

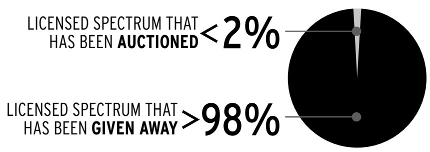
Our elected representatives, the U.S. Congress, and the U.S. President, are responsible for determining the framework of spectrum management policy. They then delegate the details to the FCC and NTIA. The basic system of spectrum allocation is "command and control." Interest groups lobby the government for spectrum rights, and the government doles them out. Federal Communications Commission Chair Michael Powell has dubbed this system "Mother, May I…" Spectrum lobbyists come to the government on bended knee pleading for spectrum lucre. One of Chairman Powell's top lieutenants visually described this system in the accompanying illustration (the dollar signs are not in the original).



Congress

Perhaps the simplest way to describe congressional spectrum policy is that the politically powerful get spectrum for free while everyone else pays. Of course, this statement is incredibly cynical. But it would be hard to disprove given the poor quality of congressional accounting for spectrum.

Congress treats spectrum giveaways as an off-budget item. This means that Congress can sanction the giveaway of tens of billions of dollars worth of spectrum rights with no trace in the budget. This resembles tax expenditures (tax breaks for select groups), which help some individuals at the expense of others, but also don't show up in the regular budget. An important difference, however, is that the



value of tax breaks is estimated by the Congressional Budget Office and the Office of Management and Budget. No such calculations are done to estimate the cost of giving away rights to use the public airwaves.

Another noteworthy feature of congressional spectrum accounting is that Congress allows licensees to pay for spectrum with in-kind public service rather than cash. But it doesn't seek to quantify or verify these public service obligations. For example, broadcasters don't pay cash for their use of the airwaves, but they claim to provide more than $8 billion dollars a year in public service. Congress has never sought to verify these claims.

Although the United States is the largest telecommunications market in the world, Germany and England have received more money from spectrum auctions than the United States. According to our calculations, less than 2% of U.S. spectrum has been auctioned. None of the auctions were designed purely to maximize revenue.

Lack of spectrum revenue is explained in part because congressional policy is not to allocate spectrum rights based on budget considerations but on telecommunications policy. In theory, this is a reasonable principle. But, in practice, it has often meant giving spectrum rights to private, for-profit companies without making them pay. At best, this amounts to industrial policy; at worst, special interest giveaways.

Where other scarce and valuable public assets are made available for commerce—such as lease rights to extract coal, cut timber, or graze herds—a combination of auctions and lease fees generate billions of dollars in public revenue.[61]

FCC

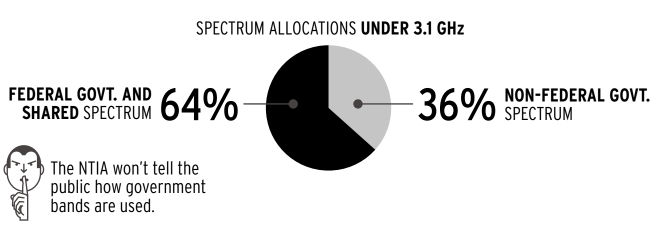
The Federal Communications Commission manages all frequencies and allocations not specifically reserved for the federal government. This includes spectrum allocated to state and local government. It does this in a two stage process. First, it allocates frequencies for specific types of services (e.g., broadcast TV, paging, taxi dispatch, and mobile telephone). Second, it assigns licenses to particular users. Prior to 1994, spectrum was assigned by comparative hearings or lotteries. Since then, a small fraction has been assigned by auction.

Good management practice requires developing a clear set of a) objectives, b) procedures to meet those objectives, and c) measurement indicators. Remarkably, the FCC has never been able to come up with a clear set of objectives. This helps explain why, despite numerous attempts, it has never been able to come up with clear guidelines to evaluate efficient spectrum use.

Even the most basic data of spectrum use—whether and to what extent assigned spectrum is actually used—has been beyond the ability or will of the FCC to measure in a systematic way that might reflect poorly on particular users. This is equivalent to the Environmental Protection Agency not measuring pollution levels of major, known polluters.

To the extent the FCC has a de facto spectrum management objective, it may best be summarized as "to preserve and increase the value of incumbents' spectrum licenses." This is manifested in the FCC's current push to give incumbents "spectrum flexibility"—the right to use spectrum in the most profitable way possible without public compensation. It is also manifested in the FCC's failure to gather information—such as spectrum utilization statistics—that might reflect poorly on incumbents.

Of course, FCC policy is far more complicated than this. But in the absence of any meaningful public involvement in spectrum policy, pursuing the interests of spectrum incumbents is the natural default policy for both the FCC and Congress.



The NTIA

An agency of the U.S. Commerce Department, the National Telecommunications and Information Administration (NTIA), manages spectrum reserved for the federal government. It is the responsibility of the NTIA to ensure that the federal government always has sufficient spectrum available for its uses. Almost every government agency, from the Department of the Interior to the Department of Defense, has parts of the radio spectrum allocated for its use. The law enforcement agencies use it for command and control of their forces. The Department of Energy uses the radio spectrum to

ON FEDERAL MANAGEMENT OF THE SPECTRUM

"Put simply, we do not manage our spectrum well."

SENATOR CONRAD BURNS, CHAIR, SENATE COMMUNICATIONS SUBCOMMITTEE[65]

"The history of U.S. spectrum policy is replete with horror stories of government stifling technological development and new wireless services to the public."

SENATOR LARRY PRESSLER, FORMER CHAIR, SENATE COMMERCE COMMITTEE[66]

"[O]ne of America's most valuable natural resources sits paralyzed, consigned to uses that time and technology have long since passed by. Old technologies are swamped with excess airwaves they don't use; newer technologies grasp for airwaves they desperately need, and promising industries of the future are asphyxiated."

WILLIAM KENNARD, FORMER CHAIR FCC[67]

"Allocating spectrum among competing commercial uses is, perhaps, the [Federal Communication Commission's] most fundamental responsibility. In starkest terms, we determine whether particular uses—indeed, entire industries—are able to exist."

SUSAN NESS, FORMER FCC COMMISSIONER[68]

"[Cities] have to buy police cars. They have to buy fire trucks. They have to buy the gas that powers those vehicles. Why don't they have to buy the fuel that powers the radios?"

DAVID WYE, *FORBES MAGAZINE*[69]

"[FCC Rulemakings]... have proven the devil's playground, where incumbent service providers booby-trap the administrative process with anticompetitive trip wires and interminable delays."

THOMAS HAZLETT, FORMER CHIEF ECONOMIST, FCC[70]

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transmit power data and commands for their power grids. Even forest rangers with the National Park Service use the airwaves every time they operate their radios. The Department of Defense is the largest single user, controlling roughly 45% of the government assignments.[62]

How much spectrum does the federal government use? This is extremely hard to say because most frequency bands are designated "shared," which means shared by both federal government and non-federal government users. And there is no straightforward way to determine how much is used by each of the sharing parties.

According to NTIA statistics, 64% of the spectrum under 3.1 GHz (the most valuable spectrum) is allocated to either exclusive or shared federal use. Under 300 GHz, the comparable figure is 95%.[63]

Shared spectrum is more common at the higher frequencies. In fact, more than 98% of the frequencies from 50 GHz to 300 GHz are allocated as "shared."[64] This is largely because neither the government nor the private sector truly knows how best to utilize many of these frequencies; the NTIA and the FCC are keeping their options open by not allocating bands to just the federal government, or vice versa. The Department of Defense has undertaken the great bulk of investment in the higher frequencies.

In comparison to the NTIA, the FCC is a paragon of accountability. The NTIA faces virtually no public oversight because there is no information on which to hold it accountable. The FCC seeks public comment on its allocations and publicly releases its database of frequency assignments. But unless Congress specifically asks for this type of information, the NTIA keeps it confidential on the grounds of national security. For example, the NTIA won't reveal what frequencies the Department of the Interior uses for fear that, through a process of elimination, enemies could figure out which frequencies the CIA uses.[71]

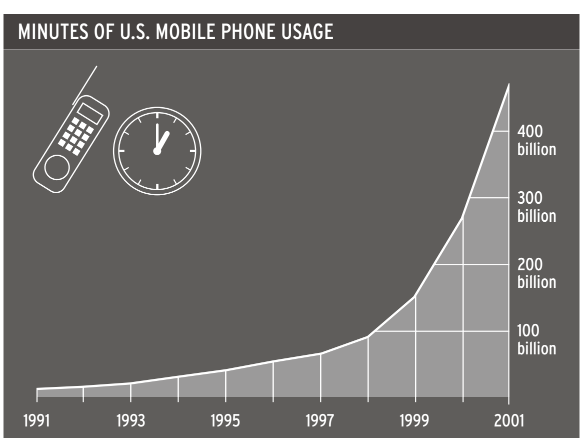
Fred Wentland, NTIA Director of Spectrum Plans and Policies, states that he would be "surprised if, on average, more than 5% of the federal government's spectrum is used." In other words, at least 95% of federal government spectrum lies unused at any given time. Other experts have given similar estimates.[72] According to conventional thinking, this is no problem because its function is to lie in reserve for emergency or peak use. But this assumes very primitive analog spectrum technology. For example, current spectrum technology allows for priority of use, which means that one user can be given priority over network capacity. The government already demands that local wired and mobile telephone operators give public safety agencies priority of use on commercial networks in case of emergency. Using the same logic, it should demand that the federal government share the public spectrum it does not use on a regular basis.

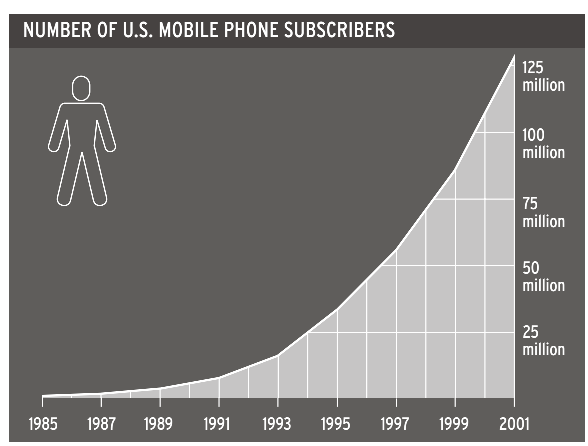
It is a curious fact that far more spectrum is allocated to the federal government than to state and local governments, despite the fact that state and local governments are responsible for fire, police, medical, and educational services. We estimate that less than 0.1% of spectrum under 300 GHz is allocated to state and local governments. Perhaps the simplest explanation of this spectrum allocation policy is that since the federal government controls spectrum allocations, it reserves the lion's share of spectrum for itself. To do otherwise would require it to pay private vendors, such as mobile telephone providers, for the use of spectrum it now gets free.

Demand for Spectrum Is Surging

Over the last hundred years, the demand for spectrum, like the supply of spectrum, has skyrocketed. No matter how much new supply of spectrum comes on the market, demand seems to increase faster.

The growth of mobile telephone minutes of usage and subscribers illustrates this growth in demand. The number of subscribers has increased from zero in 1985 to more than 125 million in 2001, and the number of minutes of usage has increased from a few billion in 1991 to more than 400 billion in 2001.[73] Wi-Fi, only a few years old, is exhibiting even faster growth, from zero units shipped in 1998 to 7.9 million in 2001 and more than 20 million units in 2002.[74]





"[N]early all of the usable radio spectrum has been allocated already...."

U.S. GENERAL ACCOUNTING OFFICE[76]

And if someone counted all the wireless devices people use today, the pattern would be similar. From just a handful of devices a decade ago, it's not at all unusual today for a family to own dozens of wireless devices, although they have been so tightly interwoven into the fabric of our lifestyles and homes that most people barely even recognize that they are there (See "Unlicensed and Licensed Spectrum").

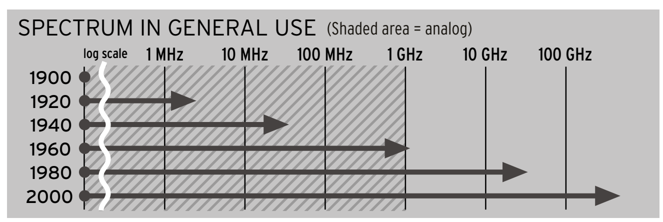
But not only is the number of services, devices, and users growing at a staggering pace, the average fidelity of communication is rising as well. For example, broadcasters are moving radio from FM to CD quality, and television from standard to high definition quality. Eventually, magazine-quality images will be the norm. As the demand for higher fidelity communications increases, so does the required bandwidth.

Which will grow faster in the future: supply or demand? It is, of course, impossible to tell. Many spectrum incumbents argue that spectrum flexibility will surely lead spectrum supply to increase faster than spectrum demand. This is a very convenient argument because it is almost invariably accompanied by lobbying for spectrum flexibility (and, ultimately, ownership rights) for themselves. The logic of the argument is that government doesn't have to worry about unjust enrichment because flexible use will greatly increase efficiency of use. And the resulting increase in spectrum supply will lead to a decrease in the price of spectrum. However, this line of reasoning assumes there isn't a lot of unfulfilled demand for spectrum. If there is, then giving incumbents spectrum flexibility would indeed create a windfall.

Have We Reached the Spectrum Frontier?

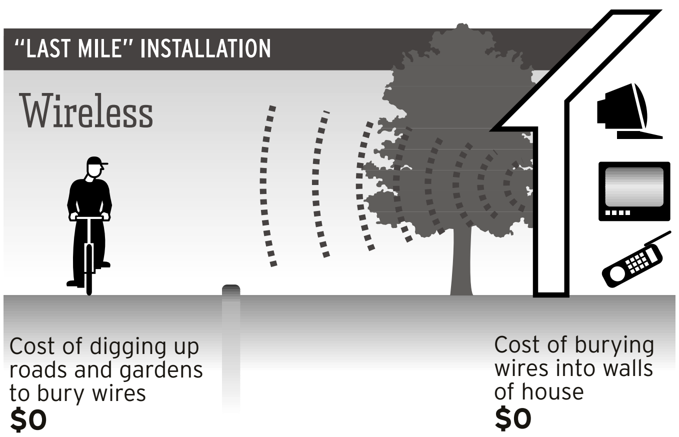
Over the last 100 years, the supply of spectrum has skyrocketed. In 1920, only the first megahertz or so was in widespread commercial or government use. By 1960, the figure was close to a gigahertz. Today, the figure is closer to 100 gigahertz, a 100,000 increase over 80 years. At the same time that the raw number of usable frequencies has increased, so has the amount of data carried by existing frequencies. Today's mobile telephone networks may reuse the same frequencies hundreds of times in a given metropolitan area. And with digital technology, the same 6 MHz that could only carry one standard definition analog TV channel in 1960 can today carry ten such channels through digital compression and multiplexing.

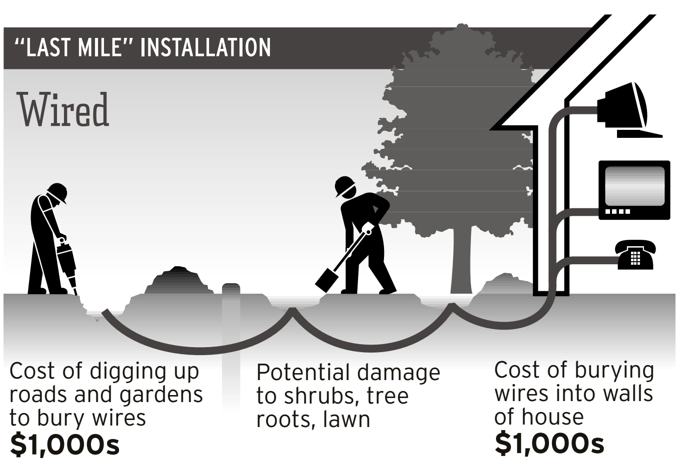
Today, we appear to have reached the spectrum frontier, at least for certain types of applications such as mobile communications. The bad news about reaching the frontier is that there are no more unsettled frequencies that can be used for mobile communications. The good news is that with digital, smart radio, and other technologies, reaching the spectrum frontier doesn't matter much anymore. There is great opportunity to use our existing frequencies far more efficiently than they have been in the past. However—and this is the great if—it requires the government to pursue policies that will maximize efficient spectrum use, especially in the lower frequencies. The history of government spectrum management has not been encouraging in this regard, as evidenced by the widespread use of analog technologies under 1 gigahertz, even at this late date.[75]



The Advantages of Wireless vs. Wired Communications

Until the 1990s, the vast majority of investment in telecommunications went into the wired network. And even in the 1990s, most telecommunications investment went into the wired network. The telecommunications boom of the late 1990s and bust of the early 2000s was a wired boom and bust. Wireless was relatively unaffected.





More than a trillion dollars has been invested in the wired network, most of it in the "last mile" linking homes to nearby telecommunication hubs. Wireless threatens to make these investments obsolete by offering a better service at a lower cost.

The current wired last mile cannot provide high fidelity (e.g., HDTV quality) Internet service to the curb of the home, let alone every room and wall outlet within the home. Hence, a high fidelity wired last mile would require the costly excavation of roads, lawns, and walls.

Why dig up streets, lawns, and walls when you can send and receive the same information for less money through the air? And for people who value mobility, wireless provides a better service. This explains why, for example, tens of millions of Americans pay twice as much for a cordless phone as a wired phone. The cost savings of wireless may be even greater in rural than urban areas. Satellite TV covers 100% of America because it costs no more to offer service to rural Montana than it does to New York City. When satellite and cable TV costs are compared, the difference can be a factor of 500 or more between a dense and a spread out population.

With today's technology, there is really no excuse for digging up lawns and snaking wires through walls in order to connect the telecommunications network from the curb to the home. It's been estimated that 55% of last mile costs lie in deploying this portion of the network infrastructure. A major reason it continues to be wired is that the government hasn't allocated enough permeable spectrum to create a wireless alternative.

With today's small, powerful, and inexpensive computing devices, wired communications becomes an increasingly poor substitute for wireless. It was one thing when wireless primarily meant watching a large stationary TV in your living room. When it means carrying around a handheld phone, laptop, or other networked device, the resistance to plugging directly into the wired network becomes much greater.

ON THE FAILURE OF U.S. TELECOMMUNICATIONS POLICY

"The truth is that there's only one way to spread broadband cheaply and quickly: wirelessly. But that's the one method not being seriously discussed in Washington."

MICHAEL BEHAR, WASHINGTON MONTHLY[77]

"[The spectrum allocation] system is inefficient, unresponsive to consumer demand, and a huge barrier to entry for new technologies anxious to compete in the marketplace."

THOMAS HAZLETT, FORMER CHIEF ECONOMIST, FCC[78]

"[W]e are still living under a spectrum 'management' regime that is 90 years old. It needs a hard look, and in my opinion, a new direction."

MICHAEL POWELL, CHAIR, FCC[79]

"What a tragedy it would be if, right as we're on the verge of the Internet migrating to inexpensive handheld devices and offering real hopes of truly democratizing the technology, the movement would be stymied by [government policy.]"[89]

WILLIAM KENNARD, FORMER CHAIR, FCC[80]

"The three most important issues before the FCC today are spectrum, spectrum, and spectrum."

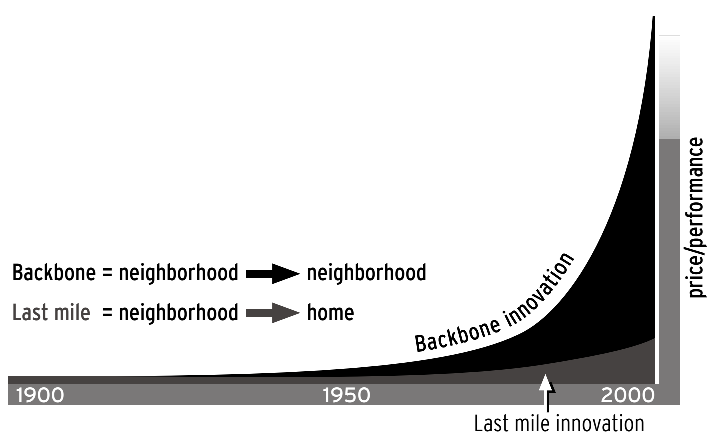
REED HUNDT, FORMER CHAIR, FCC

"...spectrum policy is the single most important issue in the telecommunications field."

SENATOR RON WYDEN, SENATE COMMUNICATIONS SUBCOMMITTEE[81]

Where Has U.S. Telecommunications Policy Failed?

The rate of innovation in the telecommunications backbone far exceeds the rate of innovation in the "last mile." As a result, last mile connections are characterized by high prices and slow speeds. A single strand of fiber optic cable carries tens of billions of bits/second, but residential Internet connections over phone or cable wires rarely reach even a small fraction of this speed. A major cause of this last mile problem is the government's failure to manage spectrum efficiently. Even today, the government spends billions of dollars to wire school rooms when it would cost a fraction as much to provide the same or a better service wirelessly. And it devotes large subsidies to wiring rural areas for broadband when the airwaves in the same rural areas lie fallow.



BACKBONE VS. LAST MILE INNOVATION

Licensed and Unlicensed Spectrum: What's the Difference?

On **licensed bands**, a user is given **exclusive** rights to use a frequency either to provide a consumer service (e.g., broadcast TV, pager, or mobile telephone) or as an input to production (e.g., train, utility, and petroleum companies). Some licensees receive separate bands for both a consumer service and input to production (See "Retail and Industrial Spectrum").

On **unlicensed bands**, any individual or company can use frequencies, but on a **shared** basis and with no guarantees against interference. Unlicensed services are typically low-power, meaning they cannot send signals very far. This allows the same spectrum to be reused many millions of times within the United States. For example, every home owner on the same street can use a garage door opener without interfering with his next door neighbor. Granting licenses to companies for exclusive use of these airwaves could either mean paying a toll for use of your garage door opener or making such services illegal because they use the license holder's airwaves without compensation.

The vast majority of non-government spectrum (more than 98%) is licensed. Much of the little spectrum that is unlicensed (under 2%) is done so on a secondary basis. That is, licensed users are given priority on the band (e.g., the U.S. Air Force) but unlicensed services (e.g., garage door openers) can share the band as long as they don't interfere with the primary use.

The primary author of this document prepared an inventory of his licensed and unlicensed devices. The following list is what he came up with. The totals are 14 licensed devices and 48 unlicensed. Data provided by the Consumer Electronics Association suggests it is fairly typical of the average American middle class family household.[82] The number of each type of device is noted in parentheses.

Licensed

Interactive (Subscription) Services

Mobile telephones (2)

One Way (Advertiser Financed) Services

TV (3)
Portable radio—battery powered (3)
Home radio—plugged into electrical outlet (4)
Car radio (2)

Unlicensed

Audio-Video Remote Controls

TV (3)
DVD (1)
CD (1)
VCR (1)
Audio System (1)
Camcorder (1)

Toys

Remote controlled car (1)
Remote controlled firetruck (1)
Remote controlled train (1)
Walkie-Talkie pair (2)

Car

Keyless car entry (4)
Garage door openers (2)
EZ-pass toll passes (2)

Home Security

Motion detector—light trigger (4)
Motion detector—alarm trigger (2)
Mobile wireless alarm keypad (1)

Computers & Telecommunications

Baby monitor (1)
Laptop infrared (1)
Cordless phones (6)
Laptop wi-fi adapter (1)
Palm pilot (2)
Wireless (wi-fi) router (1)

Other

Missing objects finder (4)
Family walkie-talkie (4)

Other common consumer wireless devices are an invisible dog fence (a signal activates a shock on a dog's collar when it leaves the home perimeter); wireless microphone; hearing aid; car, boat, hiker or private airplane navigation system (using GPS)[83]; CB radio; in-car satellite radio; stereo headphone; home video security camera; police radar detector, and home medical alert.

In addition, businesses and governments make extensive use of unlicensed devices. These include motion detectors (such as automatic retail entrance-exit doors), retail price tags and merchandise surveillance, factory floor automation, local area networks, house arrest (a form of controlled probation), airport and office radar (to detect weapons upon entry), hospital medical devices, traffic light scofflaw detection, speeding limit violation detection, utility meter monitoring, keyless office doors (e.g., with a card passed a few inches from a door), delivery and emergency vehicle destination navigation, and underground radar (to detect sewage pipes and other underground structures).

The FCC's recent approval of ultrawideband unlicensed devices is expected to lead to an explosion of unlicensed devices in the next few years, including rear auto mobile radar (to warn of bumping other cars while parking), front auto mobile radar (to warn of crashing into cars in front), and ground and wall penetrating radar (for law enforcement and construction workers).

The elimination of the need to seek government and license holder approval for new services provides unlicensed vendors with certain economic advantages that may help to explain their innovation and success:

- Rapid deployment of new technologies
- Rapid economies of scale
- No transaction costs to negotiate with government or license holders
- No monopoly rents to license holder gatekeepers
- No content controls from government and license gatekeepers

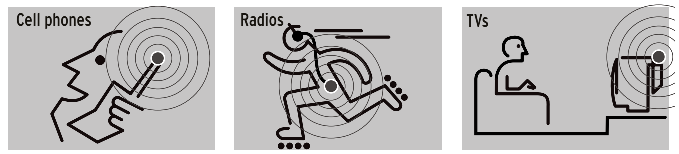
3G—An Advanced Licensed Service

The most talked about advanced licensed service is 3G mobile telephone and Internet service.[84] 1G refers to the original analog cellular telephone networks introduced in the mid-1980s. 2G refers to the conversion of the analog networks into digital networks in the mid-1990s. 3G refers to the higher speed voice and data networks now being introduced. 4G refers to the next generation, higher speed services, which are currently under development.

Wi-Fi—An Advanced Unlicensed Device

Wi-Fi (wireless fidelity) uses unlicensed frequencies to create wireless local area networks (WLANs). College campuses, airports, hotels, and other "hot spots" share high-speed Internet connections on a wireless basis.

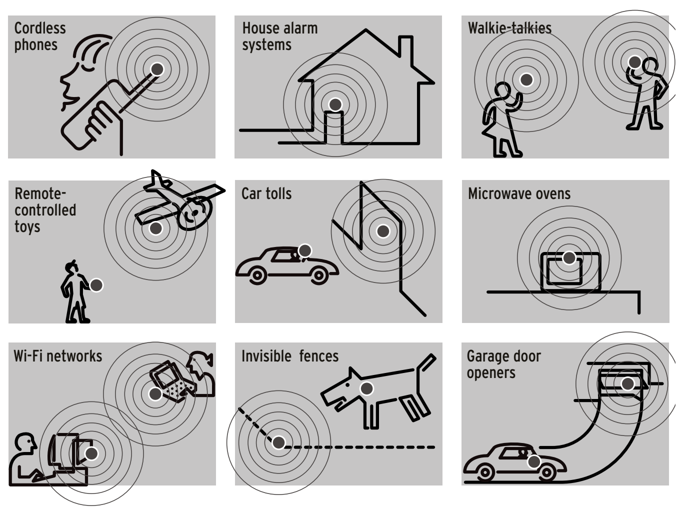
SOME DEVICES OPERATING ON LICENSED FREQUENCIES TODAY...



3G & 4G Third (3G) and Fourth (4G) generation cellular systems upgrade existing mobile telephone networks to make more efficient use of spectrum and offer higher speed Internet service.

... AND SOME DEVICES OPERATING ON UNLICENSED BANDS

Whereas licenses grant exclusive rights to wireless service providers, unlicensed spectrum is shared, allowing a virtually unlimited number of consumer devices to use the band at no charge. Unlicensed spectrum is managed like a public highway: as long as citizens obey the "rules of the road," access is open, free and shared.



Homeowners use Wi-Fi to link and use computer, audio-visual, home security, and telephone resources. Current Wi-Fi speeds are approximately 100 times as fast as state-of-the-art 3G networks. Most mobile computers now have integrated Wi-Fi circuitry.

Wi-Fi and related unlicensed devices threaten both mobile and wired telephone network operators. They allow individuals to get conventional (1G and 2G) mobile telephone services without connecting to the wired network; they allow laptop users to get high-speed Internet services without using the new 3G services; and they allow homeowners to fully benefit from their buckets of mobile telephone minutes by plugging their 2G and 3G phones into their home telephone network, bypassing the local telephone company.

ON UNLICENSED SPECTRUM—WILL THE FCC COMMISSIONERS BACK THEIR WORDS WITH ACTION?

"[T]he unlicensed bands employ a commons model and have enjoyed tremendous success as hotbeds of innovation."

MICHAEL POWELL, CHAIR, FCC[86]

"I believe the power of unlicensed spectrum services—and the corresponding rise in consumer welfare—is one of the great success stories of U.S. Telecommunications policy."

KATHLEEN ABERNATHY, FCC COMMISSIONER[87]

"We are all excited about the potential of unlicensed spectrum and the benefits it can bring to American consumers.... So I most definitely support exploring ways to make more spectrum available for unlicensed devices."

MICHAEL J. COPPS, FCC COMMISSIONER[88]

"I am hopeful that unlicensed operations will, as some have suggested, eventually provide a last-mile application to connect people's homes to the Internet, offering a real alternative to telephone wires, cable and satellite connections. I thus believe the Commission should consider a range of additional allocations for unlicensed devices.

KEVIN J. MARTIN, COMMISSIONER, FCC[89]

Open Spectrum: An Unlicensed Commons

For nearly a century, radio frequency spectrum has been treated as a scarce resource that the government must parcel out through exclusive licenses. We simply can't imagine doing anything else. Yet the assumptions underlying the dominant paradigm for spectrum management no longer hold. Today's digital technologies are smart enough to distinguish between signals, allowing users to share the airwaves without exclusive licensing.[85]

Exclusive spectrum licensing is considered necessary because the alternative would be a "tragedy of the commons": a chaotic cacophony in which no one could communicate reliably. The tragedy of the commons idea resonates with our intuitions. After all, too many sheep grazing in the same meadow will use up all the grass. Too many cars on a highway at the same time will cause traffic jams and collisions. Why should spectrum be any different?

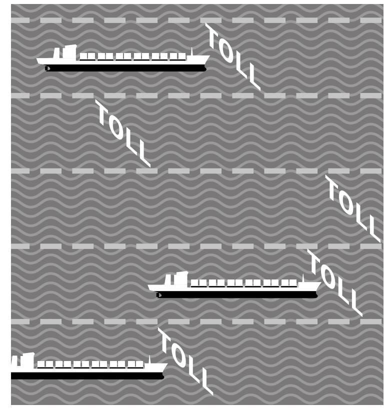
Spectrum *is* different. Technologies developed in recent decades make it practical to avoid the tragedy of the commons. "Open spectrum" is an umbrella term for such approaches. There are two primary ways to implement open spectrum technologies. The first is to designate specific bands for unlicensed devices. This is the approach that allowed Wi-Fi to flourish in the 2.4 GHz and 5 GHz bands. The second mechanism is to "underlay" unlicensed technologies in existing bands without disturbing licensed uses. This approach, epitomized by the ultra-wideband technology the FCC authorized earlier this year, effectively manufactures new capacity by increasing spectrum efficiency. Underlay can be achieved either by transmitting low-power signals within licensed bands or by employing smart radios able to identify and discriminate between competing transmissions.

With today's technology, the better metaphor for wireless is not land, but oceans. The oceans are huge relative to the volume of shipping traffic and the pilots of each boat will maneuver to avoid any impending collision (*i.e.*, ships "look and listen" before setting course). To ensure safe navigation, we have general rules defining shipping lanes and a combination of laws and etiquette defining how boats should behave relative to one another. A regulatory regime that parceled out the oceans to different companies, so as to facilitate safe shipping, would be overkill. It would sharply reduce the number of boats that could use the seas simultaneously, raising prices in the process.

The same is true with spectrum. Allowing users to share spectrum, subject to rules that ensure they do so efficiently, would be far more effective than turning more spectrum over to private owners.

Another analogy to wireless communication in the radio-frequency spectrum is wireless communication in the acoustic spectrum, otherwise known as speech. Imagine a group of people in a room. Experience tells us that everyone can carry on a conversation with his or her neighbor simultaneously, even with music playing in the background, so long as people speak at a normal volume. If someone starts yelling, he or she will drown out other speakers, who will be forced to speak louder themselves in order to be heard. Eventually, some portion of the room simply won't be able to communicate over the background noise and each additional person who starts yelling will reduce the total number of conversations.

We could call that a "tragedy of the commons." We could enact laws giving only some individuals the right to speak during defined times, ensuring they can shout as loud as they want without interference. But that would clearly be an unnecessary solution with significant negative consequences.



AN ANALOGY: PRIVATIZING THE OCEANS

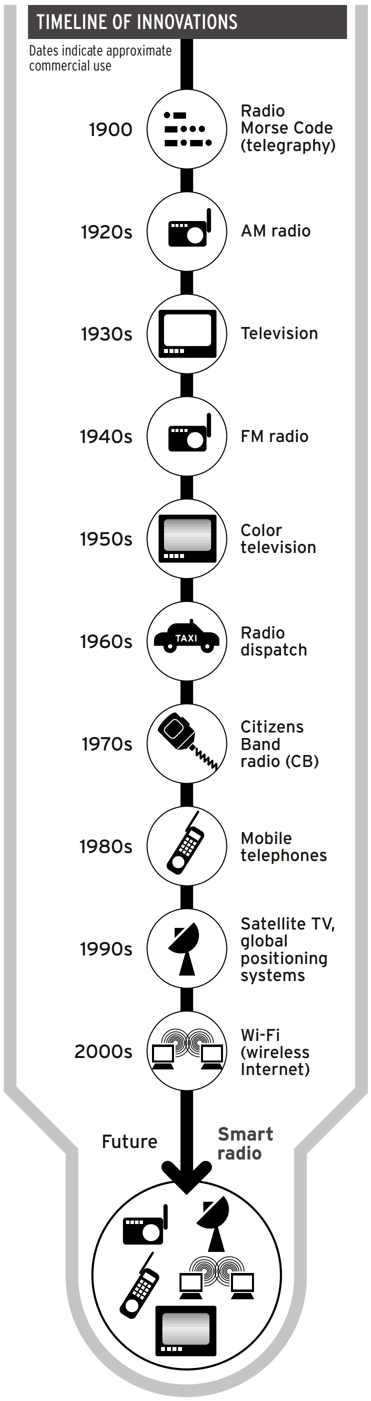
A commons, like the air we breathe and the language we speak, is a shared, renewable resource. It is open to all. It is not completely free or inexhaustible, but it can seem that way if individuals follow rules to prevent overuse. A commons is entirely compatible with competitive capitalism. The marketplace occurs among users of the commons; the commons itself cannot be bought or sold.

In short, a spectrum commons appears to have important economic advantages. It lowers barriers to entry, thus creating strong incentives for competition and innovation. And it lowers transaction costs—it is no more economical to charge every time people use the electromagnetic spectrum to open their garage doors than it is to charge every time they use the acoustical spectrum to utter a spoken word. These economic factors help explain why Wi-Fi and other unlicensed technologies are today at the center of telecommunications competition and innovation.

What Is Smart Radio?

There have been many efficiency-enhancing breakthroughs in spectrum technology in recent years. For example, the advent of digital technology facilitated the development of compression (eliminating redundant information), multiplexing (sharing unused communications capacity in a single communications channel), and spread spectrum (sharing unused communications capacity across multiple communications channels). But none of these technologies appears to be as revolutionary as smart radio, which not only promises a huge increase in spectrum efficiency, but also a revolution in spectrum policy management. The advent of smart radio may be to spectrum technology what the advent of the transistor was to computer technology and the advent of the telephone was to communications technology: the beginning of an unprecedented explosion of technological and policy innovation.

Smart radio, as the name implies, adds context sensitive intelligence to signal processing. Think of the difference between a human ear and a microphone. A human ear has a fine-tuned ability to discriminate between noise and signal. In a room full of conversations, it can focus on a particular conversation of interest. A microphone,



in contrast, treats all conversations equally and generates unwanted background noise if all other people in the area covered by the microphone don't keep quiet. This is extremely inefficient because a room, instead of supporting many conversations, can now only support one. Smart radio allows many different "conversations" to share the same spectrum.

One of the most important features of smart radio is that it can not only frequency hop across large bands of spectrum, but also, like a universal translator, understand and speak in the wireless language of each of the bands it uses.[90] A single smart radio has the flexibility to provide all the wireless services of hundreds of dumb radios, including FM radio, broadcast television, cellular telephone, cordless phone, and remote control.

Economic Advantages of Smart Radio

Smart radio can create an "open network" and allow the dynamic sharing of frequencies. Consumers and vendors can easily switch frequencies, thus diminishing the monopoly power of license holders. They can also spread their equipment costs across many services and frequency bands, thus reducing the total cost of spectrum equipment. It's like having one personal computer that can perform word processing, database, spreadsheet, graphic design, video editing, telephone, television monitor, stereo, Internet, and other functions rather than having a separate device for each of those functions.

Policy Implications of Smart Radio

Smart radio fundamentally changes the economics of licensing. Today, there are substantial efficiencies gained from granting long-term licenses of as much as a decade or more. This is because license holders need to recoup substantial investments in specialized (i.e., dumb) spectrum equipment. In the future, if both transmitters and receivers can easily be reprogrammed to use a variety of frequencies, the efficient term of a license may drop to microseconds.

Smart radio, with its superior ability to distinguish signal from noise (because signals speaking different "languages" are not mistaken for noise), also allows for much more efficient management of interference. A "listen before talk" protocol, for example, assumes that a radio can first distinguish between signal (conversation) and noise (unused spectrum). This capacity to distinguish between signal and noise allows different users, such as licensed and unlicensed users, to coexist in ways not previously possible.

Politics of Smart Radio

Incumbent license holders will strongly oppose any use of smart radio that reduces their monopoly power over both consumers and vendors; that undermines their economic rational for long-term licenses with property rights; or that provides an economic rationale for them to share underutilized frequencies with other users (such as low-power or unlicensed users).

Example of Smart Radio

The U.S. Department of Defense has invested substantial sums in smart radio so that military personnel can go anywhere in the world and communicate over the airwaves, even when other countries have allocated spectrum in very different ways than in the U.S. The Defense Department has a track record of developing breakthrough wireless technologies, including radar, radio, and spread spectrum. Its financing of smart radio may one day prove as important as its early financing of the Internet.

Is Spectrum Used Efficiently?

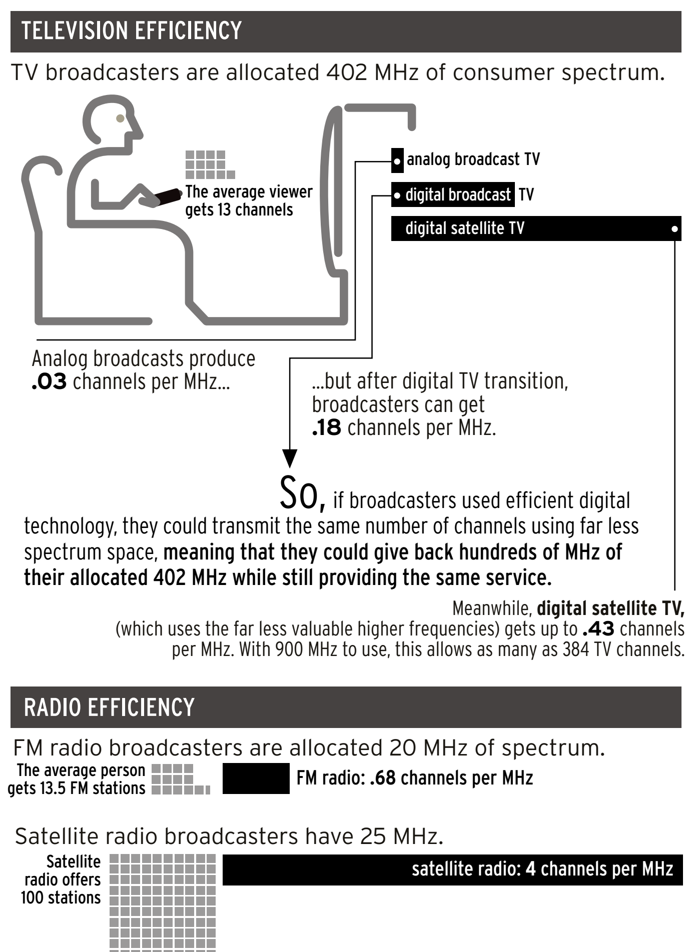
As evidenced by the tens of billions of dollars bid at auctions for small slivers of the radio spectrum in the United States and other countries,[91] the airwaves are currently an extremely scarce resource. Much of this shortage is due to the government's highly inefficient system of spectrum management. This system gives incumbent license holders minimal incentive to use their spectrum efficiently. It serves to protect the interests of incumbent license holders from competition and innovation. And, it gives the status quo a privileged legal position, so that if there is controversy and conflict among powerful incumbent license holders, any one of them can exercise a veto over change. At a time when technology is leaping along at fantastic rates of innovation, this regulatory inertia and protectionism is a disaster.

The FCC has never been able to agree on a measure of efficient spectrum use,[92] in part because any attempt to do so would result in a furious response by any incumbent who did not come out well in such an evaluation. No politically astute FCC official would needlessly inflict this abuse on himself.

There are, of course, no perfect measures of performance. Standardized tests of student and school performance, for example, are inherently flawed measures of education performance, yet they are the centerpiece of federal education reform. Most people would agree that it is better to have some measures of individual performance, even if flawed, than no measure at all.

Here we have employed an easy-to-understand, albeit modest, definition of efficiency: number of channels of a given type of service per unit of spectrum. This gives us an efficiency rating for the production of standard definition TV channels of .03 channels/MHz for over-the-air analog broadcast TV; .18 channels/MHz for over-the-air digital broadcast TV;[93] and .43 channels/MHz for digital satellite TV.[94] The comparable figures for broadcast radio are .675 channels/MHz for over-the-air FM radio and 4.0 channels/MHz for satellite XM radio.[95]

Of course, a more sophisticated view of efficiency would include economic variables. According to advocates of the so-called "Negroponte Switch," for example, satellite TV could provide the same local channels as today's digital broadcast TV, while also freeing up the broadcasters' spectrum for a cornucopia of new services and even hundreds of billions of dollars of auction revenue. Currently, about 90% of Americans receive live TV signals from either a satellite or cable hookup.[96]



ON EFFICIENT USE

"Television is the wasteland of the spectrum."

MARK LEWYN, *BUSINESS WEEK*[99]

"Today, local governments use… prime spectrum for police and fire dispatching and other uses, but they use it extremely poorly. Their analog radios are so archaic they typically swallow at least 10 times more spectrum per call than a modern cell phone does. The public networks are so inefficient that 80% of local governments turn to the crowded private airwaves for backup."[100]

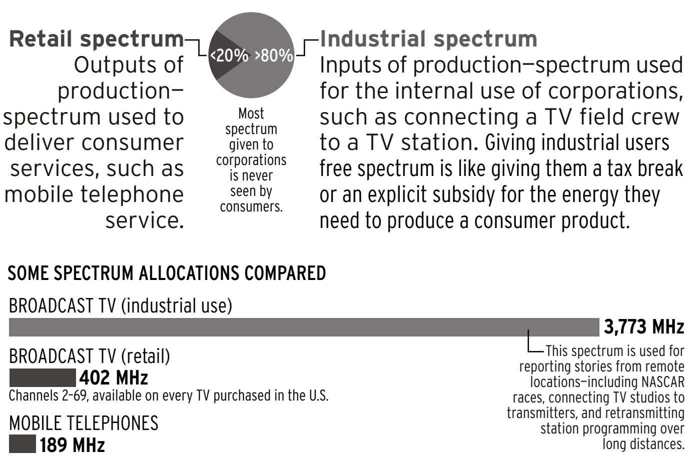
SCOTT WOOLLEY, *FORBES MAGAZINE*[101]

Retail and Industrial Spectrum

Retail spectrum is defined as spectrum used to provide **outputs of production** such as mobile telephone service, broadcast TV, and Wi-Fi.

Industrial spectrum is defined as spectrum used to provide **inputs of production** such as linking a TV field crew to a station or allowing a utility company employee to converse with the home office in the field.

Less than 20% of spectrum is used for retail as opposed to industrial purposes. An example of the distinction is broadcast TV. The retail spectrum is the 402 MHz devoted to providing channels 2-69 (excluding channel 38, which is not publicly usable). The industrial spectrum is the 3,773 MHz used for reporting stories from remote locations, connecting TV studios to TV towers, retransmitting station programming to satellite stations hundreds of miles away, and anything else that can help reduce broadcasters' internal telecommunications costs.[97] One colorful use of this spectrum is to outfit cars in NASCAR races with video cameras wirelessly connected to a TV producer. There are many other sports events, such as golf tournaments and alpine skiing, where free access to dozens of wireless video links is similarly useful.



Why do broadcasters, cable companies, and telephone companies have access to so much industrial spectrum as opposed to, say, retail stores, financial service firms, and manufacturers? The answer probably has less to do with any compelling public interest argument and more to do with the close relationships these industries have with the FCC, so that they were well-positioned to claim spectrum when it first became available. The early bird catches the worm. Congress, of course, is also a factor. The fact that local members of Congress are terrified of displeasing their local broadcasters—who, via control of political ads and news, largely control their public images—may be another factor.[98]

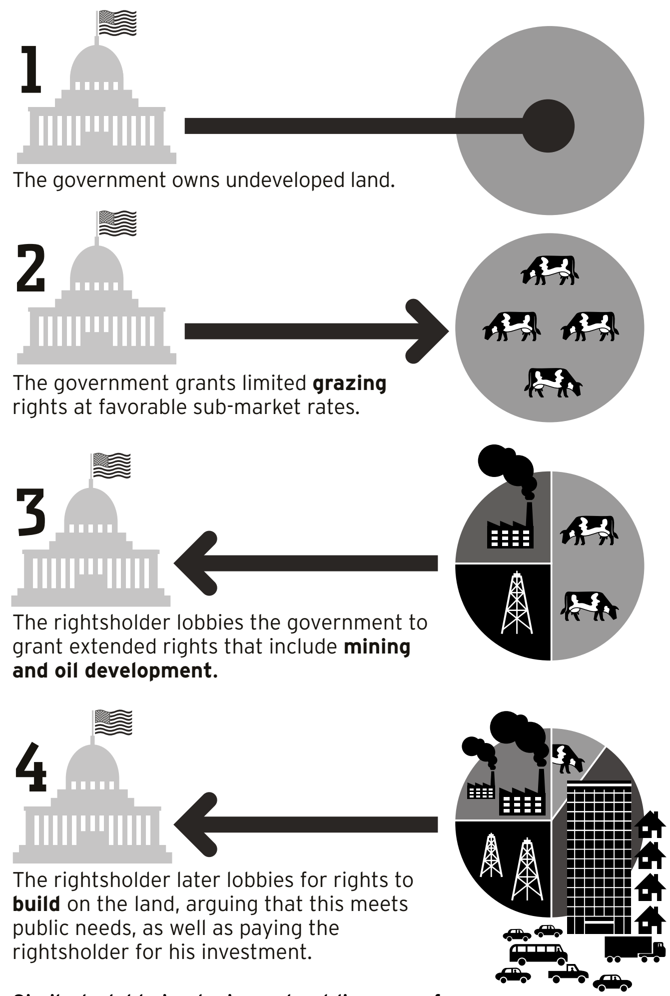
The Politics of Spectrum

The basic strategy of spectrum licensees is to get a narrowly defined license for some public purpose, then gradually win the equivalent of full property rights to that spectrum, often called "spectrum flexibility." Common arguments to get your foot in the door have included public safety, public education, diversity, and foreign threats. Once a license is acquired, the incumbent license holder knows the government will never take it back. Original promises are forgotten, and a push begins for additional and more profitable spectrum rights that will enhance the value of the license. Common justifications for enhancing the value of licenses are "spectrum flexibility," "market-based allocation," "deregulation," "eliminating red tape," and "reducing regulatory uncertainty."

As a practical matter, however, lobbyists know they cannot just ask for billions of dollars of public property rights without some type of public compensation. At a minimum, they need to provide political cover for politicians and regulator willing to give them something for nothing. Some of the classic lobbying strategies, often used simultaneously, are to:

- provide evidence that the spectrum rights they want really aren't valuable,
- claim that they already paid for the rights they want in secondary markets when they purchased licenses from earlier license holders,
- claim that they are providing "public service" proportional to the value of the rights they want,
- frame their requests for spectrum rights in terms, such as modifying a logarithmic equation, that the public does not understand, and
- ask for spectrum rights over time in small enough quantities that the giveaway stays under the public radar.

To help understand **how spectrum lobbying works,** here's an analogy with federal land grants:



1 The government owns undeveloped land.

2 The government grants limited **grazing** rights at favorable sub-market rates.

3 The rightsholder lobbies the government to grant extended rights that include **mining and oil development.**

4 The rightsholder later lobbies for rights to **build** on the land, arguing that this meets public needs, as well as paying the rightsholder for his investment.

Similarly, lobbying by incumbent licensees for spectrum 'flexibility' can turn a limited-term, low-value TV license into a permanent and far more valuable mobile Internet service.

Let's focus on the fifth approach, which the television broadcasters have practiced to perfection. As an analogy, consider the giveaway of rights to use public lands. In the beginning, the public land is unused. Then the government grants a short-term license at sub-market rates for cattle grazing. Over time, the licensee lobbies the government for longer-term licenses with no fee increase and additional land usage rights, including mining and oil development. Ultimately, the licensee wins perpetual rights and the right to build condos and office buildings throughout the park. The result is land used

ON THE CONSEQUENCES OF SPECTRUM POLITICS

"The bottom line is that spectrum is just as much a national resource as our Nation's forests. That means it belongs to every American equally. No more, no less. If someone wants to use our resources, then we should be fairly compensated."

SENATOR BOB DOLE, FORMER MAJORITY LEADER, U.S. SENATE

"Not charging for spectrum is a national disgrace. It's as though you stood in front of the FCC and burned hundreds of millions of dollars."

HENRY GELLER, FORMER CHIEF COUNSEL, FCC [103]

"[T]he FCC is in danger of building an infrastructure and protectionist program for information smokestacks and gas guzzlers."

GEORGE GILDER, *FORBES MAGAZINE*[104]

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much more efficiently to meet market demand. But the transfer of rights from the public to private sector is achieved via lobbying rather than payment in a competitive auction.

Of course, this doesn't happen with contractors who use federal lands because the public understands real property and would be enraged by a giveaway of public assets on this scale.[102] But this is exactly what has happened with television licenses. TV Broadcasters started with 3-year licenses to 6 MHz of spectrum, significant public interest obligations, and comparative renewals. Over time, they won de facto ownership rights over their first 6 MHz of spectrum. With the advent of digital TV, they added another 6 MHz to their license, no fixed return date or interest payments for the additional 6 MHz, and significant new flexibility. Ultimately, it can be expected that they will try to win full ownership rights, including the right to provide mobile Internet service or any other service in most demand by the market.

ANALOGY BETWEEN ACOUSTIC AND ELECTROMAGNETIC SPECTRUM

Conclusion: A Call for Spectrum Policy Humility

Wireless communication technology is in the midst of a revolution with profound implications for spectrum policy. Largely due to the computer revolution, the information carrying capacity of the spectrum is exploding. With this explosion comes a new spectrum economics and a crying need for a new spectrum policy. We believe a primary model for this new regulatory regime should be the regulation of the acoustic spectrum, commonly known as speech. This regime is characterized by a commons and First Amendment values.

Spectrum capacity is exploding on many fronts. Consider the evolution of wireless telephone service. Fifty years ago, a large metropolitan area might have one transmitter (a single "cell") offering wireless telephone service to public safety personnel such as police. A single conversation could require a dedicated 240 kHz channel. Today, perhaps 100,000 telephone calls can be handled in the same spectrum previously designated to handle only one call.

The reasons for this explosion in capacity are many. Smaller cell size and directional antennas allow spectrum in a given geographic area to be reused. Today, there may be as many as 1,000 mobile telephone cell sites in an area previously having only one. Each of these cells, in turn, may be subdivided into discrete sectors radiating from a directional antenna. The transition from analog to digital technologies, including digital compression (eliminating redundant information), packet switching (utilizing the empty spaces in spectrum, such as the pauses during conversations), and new modulation schemes (making it possible to cram more bits of data into a single hertz), have also made it possible to transmit as many as ten conversations in the spectrum previously able to handle only one. Channels may be as small as 12.5 kHz and each carry multiple calls.

Yet all these advances may be little compared to what's likely to happen in the next decade. Another increase in spectrum capacity by a factor of 100,000 is quite plausible.

One of the biggest changes on the horizon is the advent of smart receivers, which begin to give radios the signal discriminating power of the human ear. Consider the communication environment in a football stadium.[105] There is an announcer that communicates with all 100,000 fans. But this doesn't preclude the fans from talking to the people next to them, even if the announcer is

ON THE LINKS BETWEEN SPECTRUM TECHNOLOGY, ECONOMICS, AND POLICY

"Change the technology, and the economics and the law of spectrum use must change, too."

ELI NOAM, PROFESSOR OF ECONOMICS AND FINANCE, COLUMBIA UNIVERSITY[107]

"We are at the dawning of what will likely be the most significant technical revolution in radio technology in 70 years. Put briefly, Moore's Law is going to meet Marconi's transmitter. Radio improvements in microprocessors will soon make possible radios that are much smarter and more flexible than those in use today.... Shackling these advanced radios with the static spectrum management of the past will severely limit the benefits that can be gained from them."

KEVIN KAHN, INTEL CORPORATION[108]

"...the heart of a new spectrum policy should be to create new incentives to use spectrum in an innovative way, in a creative way, to share it, rather than in effect pull it close to you and hoard it. Essentially, today's system encourages people just to hold everybody hostage and get the best ransom you can for it."

SENATOR RON WYDEN, SENATE COMMUNICATIONS SUBCOMMITTEE[109]

speaking. Tens of thousands of overlapping conversations going on simultaneously can occur on the same very narrow band of frequencies, even as the announcer speaks.

In contrast, today's spectrum policy allocates spectrum as though the only person who can speak in the stadium is the announcer; everyone else must remain quiet. The justification is that if there were any other conversation going on, it would conflict with the announcer's communication.[106] The reason this doesn't happen in a football stadium is that humans are smart receivers. They can distinguish between messages coming from left, right, front, back, up, down, close, and far away, and tune into just the message they want while ignoring the others. This requires a large amount of both processing power and software intelligence, something radio receivers have never had but are in the process of acquiring.

In fact, it is possible that smart receivers could acquire even more discriminating intelligence than human beings. In a crowded place with many conversations going on, human beings may be able to focus on one conversation but have limited abilities to tune out the other conversations. Smart receivers may be able to tune out this interference far better than human beings can.

What does this imply for spectrum policy? It suggests that giving a legal monopoly on speech (i..e, an exclusive license) to a handful of high-powered announcers might not be such a good idea. Sure, these announcers might have incentives to put sensors on every seat in every football stadium, office, and home in America to detect when Americans are speaking and charge for it. But is this really an efficient and socially desirable way to structure all or even most speech? And do we really want to give the beneficiaries of such speech licenses the huge windfall that would come with monopoly control of speech?

Admittedly, from the standpoint of today's dumb receiver technology, it may look like we have no other policy option. But if the assumptions underlying today's dumb spectrum communications environment are on the verge of changing, it would be tragic to give the licensees of spectrum permanent and complete property rights. For these reasons, we propose a spectrum policy premised on humility—the recognition that the technological and economic underpinnings of spectrum policy may change. Sure, licensees should be given the flexibility to provide what the market demands. But the licenses should not be permanent or even have a presumption of renewal unless the economics of spectrum investment (see "Smart Radio") require it. And if, as expected, the economics of electromagnetic and acoustic spectrum continue to converge, so should the regulatory regime.

Appendix A: *Rejected Auction Values with Reasons*

	DATE AUCTION ENDED	INCUMBENTS IN BAND	LICENSE OR SPECTRUM BLOCK PARTICUARLY SMALL	LICENSE BANDWIDTH PARTICUARLY SMALL	LICENSED SPECTRUM ONLY COVERS A PORTION OF COUNTRY	VALUATION SUPERCEDED BY MORE RECENT AUCTION	RESTRICTIVE INTERFERENCE PROTECTIONS	RESTRICTIONS ON USE	POST AUCTION INDICATION PLANNED USE DID NOT MEET EXPECTATION
Nationwide Narrowband PCS.	7/9/94		X						
Interactive Video and Data Services (IVDS).	7/29/94								X
Regional Narrowband PCS.	11/8/94		X						
Broadband PCS: A and B Block.	3/13/95					X			
Broadband PCS: C Block.	5/6/96					X			
Multipoint/Multichannel Distribution Services (MDS or MMDS).	3/28/96	X							X
900 MHz Specialized Mobile Radio Service (SMR).	4/15/96	X		X					
Direct Broadcast Satellite 110 degrees (DBS).	1/25/96							X	
Direct Broadcast Satellite 148 degrees (DBS).	1/26/96				X			X	
Broadband PCS: C Block Reauction.	7/16/96					X			
Broadband PCS: D, E, & F Block.	1/14/97					X			
Cellular Unserved Auction.	1/21/97				X				
Wireless Communications Service (WCS).	4/25/97						X		
Digital Audio Radio Service (DARS).	4/2/97							X	
800 SMR	12/8/97								
Local Multipoint Distribution System (LMDS).	3/25/98								
220 MHz.	10/22/98	X	X	X					
VHF Public Coast (VPC).	12/14/98				X			X	
Location and Monitoring Service.	3/5/99						X	X	
C, D, E, and F Block Broadband PCS Licenses.	4/15/99					X			
Local Multipoint Distribution System (LMDS) Reauction.	5/12/99				X				
Phase II 220 MHz Service Spectrum Reauction.	6/30/99	X	X	X					
"Closed" Broadcast Auction.	10/8/99				X			X	
929 and 931 MHz Paging Service.	3/2/00			X					
Broadcast Auction.	10/8/99				X			X	
Broadcast Auction.	3/24/00				X			X	
39 GHz Auction.	5/8/00								
700 MHz Guard Band Auction.	9/21/00	X					X	X	
800 MHz SMR General Category Service Auction.	9/1/00	X		X					
C and F Block Broadband PCS License Reauction	1/26/01								
800 MHz SMR Service (Lower 80 Channels) Auction.	12/5/00	X		X					
700 MHz Guard Band Reauction.	2/21/01	X					X	X	
VHF Public Coast and Location and Monitoring Service (LMS) Auction.	6/13/01				X		X	X	
Paging Auction.	12/5/01			X					
Narrowband PCS Auction.	10/16/01		X	X					
Multiple Address Systems Auction.	11/27/01		X	X				X	
Multi-Radio Service Auction.	1/17/02				X				
Cellular RSA Auction.	6/4/02				X				
Blanco Texas Broadcast Auction.	7/12/00				X				

Notes: 1) This list accounts for all completed FCC auctions as of July 30, 2002. 2) Auctions in **Bold** were accepted for valuation.

Appendix B: *Delphi Survey on Demand for Spectrum*

We are trying to estimate the amount of spectrum that would be purchased to provide additional services (as opposed to being used to reduce the cost of providing current services) as a function of its price. For the purposes of this exercise, please assume that economic conditions are normal, that the spectrum that is available is unrestricted as to use except for the requirement not to interfere with the use of spectrum on other frequencies and is reasonably – but not necessarily ideally – suited for the purposes you anticipate it being used for, and that "title" to it is as effective as the present title of cellular companies to their spectrum.

Because spectrum below about 3.5 GHz seems to be better suited for mobile uses, we want to estimate the amount of spectrum that would be purchased separately for spectrum below this frequency and for spectrum above it. (If you believe that there is a better break point to use, please let us know.) We will consider the lower frequencies first.

For the questions below, further assume that the MHz cover the entire United States and are free of incumbent users. Please comment separately if the use envisioned could work well with less than national allocations or coexist with existing users. If the spectrum could not be put to economic use in the next decade, please note this.

Questions

- What is the maximum (i.e., market-clearing) price per MHz-Pop that such spectrum below 3.5 GHz could sell for and still have 100 MHz sold and put to economic use during the next decade (and what are the main uses that this spectrum would be devoted to)?
- To what level (below the one you gave in answer to question 1) would price have to be reduced to have an additional 200 MHz of spectrum below 3.5 GHz be put to economic use during the next decade (and what would the main additional uses be)?
- To what level (below the one you gave in answer to question 2) would price have to be reduced to have an additional 500 MHz of spectrum below 3.5 GHz be put to economic use during the next decade (and what would the main additional uses be)?
- To what level (below the one you gave in answer to question 3) would price have to be reduced to have an additional 1,000 MHz of spectrum below 3.5 GHz be put to economic use during the next decade (and what would the main additional uses be)?

Now we wish to ask similar questions for spectrum above 3.5 GHz. Note that we have asked about some different numbers of MHz in this range.

- What is the maximum (i.e., market-clearing) price per MHz-Pop that such spectrum above 3.5 GHz could sell for and still have 500 MHz sold and put to economic use during the next decade (and what are the main uses that this spectrum would be devoted to)?
- To what level (below the one you gave in answer to question 5) would price have to be reduced to have an additional 2,000 MHz of spectrum above 3.5 GHz be put to economic use during the next decade (and what would the main additional uses be)?
- To what level (below the one you gave in answer to question 6) would price have to be reduced to have an additional 5,000 MHz of spectrum above 3.5 GHz be put to economic use during the next decade (and what would the main additional uses be)?
- To what level (below the one you gave in answer to question 7) would price have to be reduced to have an additional 10,000 MHz of spectrum above 3.5 GHz be put to economic use during the next decade (and what would the main additional uses be)?
- Finally, do you have any comments on these questions or your answers to them?

Notes

Introduction

[1] As of December 31, 2001.

[2] Speech delivered by Michael K. Powell, Chair of the FCC, "Broadband Migration III: New Directions in Wireless Policy," October 30, 2002.

[3] The classic overview of spectrum technology, economics, and public policy is Harvey J. Levin, *The Invisible Resource*, Baltimore: Johns Hopkins Press, 1971. The Congressional Research Service periodically publishes spectrum guides, including "Radiofrequency Spectrum Management," 97-218 SPR, April 23, 1998. For a recent spectrum technology primer written in accessible language, see Carl Weisman, *The Essential Guide to RF and Wireless, 2nd Edition*, Upper Saddle River, NJ: Prentice-Hall, 2002. For a guide to spectrum allocations, see Bennett Kobb, *Wireless Spectrum Finder; 7th Edition*, New York City: McGraw-Hill, 2001. For the currently most publicized and debated overview of spectrum policy issues, see the *Spectrum Policy Task Force Report*, Washington, DC: Federal Communications Commission, November 2002.

[4] For an online copy of the chart, see the National Telecommunications and Information Administration web page.
Link: http://www.ntia.doc.gov/osmhome/allochrt.pdf.

[5] Communications Act of 1934, Title III, Section 301.

Part 1

[6] Among the most common radio devices are: FM radio (88-108 MHz), Broadcast television (54-72 MHz, 76-88 MHz, 174-216 MHz, 470-608 MHz, 614-806 MHz), Mobile telephones (various bands from 806-940 MHz, 1850-1990 MHz), Cordless phones (902-928 MHz, 2400-2483.5 MHz), Highway toll tags (902-928 MHz); Garage door openers (300-322 MHz); and Wi-Fi (2400-2483.5 MHz). Many devices, such as cordless phones and Wi-Fi, share the same band.

[7] A brief discussion of technological considerations of the radio spectrum can be found in the Congressional Research Service Report for Congress, "Radiofrequency Spectrum Management," 97-218 SPR, April 23, 1998.

[8] We show a dip in our value of the airwaves graph to indicate that antenna size and other considerations may lead frequencies below 30 MHz to drop in value.

[9] The FCC publishes a guide to limits on power density exposure for different frequencies. The strength of a signal's power level decreases geometrically with distance from the transmitter. See Carl J. Weisman, *The Essential Guide to RF and Wireless*, 2nd Edition, Upper Saddle River, NJ: Prentice Hall, 2002, p. 267.

[10] But increasing power levels does not come without cost. For example, in order for a mobile phone operating at 4 GHz to have the same performance as a mobile phone operating at 2 GHz, the 4 GHz phone would require 4 times the amount of power. Another mobile phone at 8 GHz would require 16 times the amount of power of the 2 GHz phone. With mobile communications, power and battery life are enormous concerns. Would you be a) willing to carry around a "mobile" phone with a battery 16 times its present size, or b) satisfied with a mobile phone that has a battery life of 1/16th its present duration?

[11] Frank Box et al., "Methodology for Evaluating U.S. Spectrum Usage Between 30 MHz and 30 GHz," contract report for the Federal Communications Commission, McClean, VA: MITRE, July 1995.

[12] "The Hidden Costs of Getting Revenue from Broadcast Spectrum," unpublished white paper handed to members of Congress, Washington, DC: National Association of Broadcasters, July 1995.

[13] Mary Greczn, "FCC Tees Up Spectrum Rulemaking and UWB Follow-up," *Communications Daily*, February 7, 2003, p. 5.

[14] The Empire State Building was sold in March, 2002 by Donald Trump to Empire State Building Associates for $57.5 million, but is estimated to be worth $1 billion without the restrictions included in its 114-year master lease, which only provides for payments of $1.97 million per annun. Link: http://www.conway.com/ssinsider/bbdeal/bd020325.htm.

[15] Based on stock market capitalization.

[16] Based on 147.3 million gold ounces valued at $309.20 per ounce. Link: http://www.globalsecurity.org/military/facility/fort-knox-depository.htm.

[17] As reported in *U.S.A Today*, *Forbes Magazine* recently listed Bill Gates as the world's wealthiest person with a net worth of $52.8 billion. Link: http://www.usatoday.com/html/money/general/2002/03/01/richest.htm.

[18] Temporary Assistance for Needy Families (TANF), a welfare program, is the new name for Aid to Families with Dependant Children (AFDC). According to the Administration for Children and Families (ACF) home page, year 2000 TANF spending was $24 billion. Link: http://www.acf.dhhs.gov/programs/opre/ar2001/chapter01.doc.

[19] Figures for United States federal spending in 2003 on Medicaid and National Defense are taken from the "Citizen's Guide to the Budget." These figures are from a chart *How Your Tax Dollars Are Spent*, and are based on a projected budget of $2.1 trillion, with Medicaid accounting for 7% and National Defense accounting for 17%.
Link: www.whitehouse.gov/omb/budget/fy2003/cguide.pdf.

[20] A number of highly restrictive auctions have been held for broadcasting licenses, but none of the auctions represent an accurate estimate of the value of broadcast television licenses.

[21] This method was based upon the sale of station WNYC in New York. This station was being converted from an educational station to a commercial one, making the value of the station essentially equal to the value of the license and its other tangible assets. See the letters of Robert M. Pepper, Chief, FCC's Office of Plans and Policies, to Senator Joseph I. Lieberman et al, May 5, 1995 and September 6, 1995.

[22] Television advertising revenue is taken from the Television Bureau of Advertising. Link: http://www.tvb.org/rcentral/index.html.

[23] A useful discussion of the relevance of over-the-air broadcasting is contained in Thomas Hazlett's "The U.S. Digital TV Transition: Time to Toss the Negroponte Switch." Subscription rates for cable and satellite broadcasting are contained on page eight. Link: http://www.aei.brookings.org/publications/working/working_01_15.pdf. James Ashurst of the Satellite Broadcasting and Communications Association provided relevant figures for satellite subscription rates for local services packages.

[24] In FCC comments filed November 10th, 1998 regarding ET Docket No. 95-18, NAB wrote: "The reduction of BAS [Broadcast Auxiliary Spectrum] channel bandwidth to 12 MHz, which an 85 MHz allocation for BAS would entail, generally would not require replacement of trucks, towers, and other equipment apart from the radios used for transmission and receipt of the ENG signal…the equipment that would be needed to transition to 12 MHz channels would only be of sufficient quality to replicate the present analog ENG transmissions."

[25] In FCC comments filed November 13th, 2001 regarding IB Docket 01-185, SBE cites new ICO Global Communications estimate of the cost of clearing broadcasters from the 1900-2025 MHz band at $200 million.

[26] See Bennett Kobb's *Wireless Spectrum Finder*, New York: McGraw Hill, 2001, p. 228.

[27] Radio advertising revenue is taken from a news release of the Radio Advertising Bureau entitled "Radio Industry Winds Up 2001 off 7% in Ad Sales." Link: http://www.rab.com.

[28] According to independent companies, research of the NAB, and comments filed with the FCC.

[29] Radio penetration statistics are taken from the *Radio Marketing Guide* and *Fact Book for Advertisers*, 2001-2002. Link: http://www.rab.com/station/marketing_guide/rmgfb72dpi.pdf.

[30] http://www.xmradio.com.

[31] Note that this analysis ignores the negative effect that the auctioning of more transponders would have on individual transponder prices. Hence, this is a marginal analysis.

[32] William Safire, "Spectrum Squatters," *The New York Times*, October 9, 2000. p. A21.

[33] *Congressional Record*, May 9, 1996, p. S4928. Also, Serial #104-635, pg. 1.

[34] General Accounting Office, "Comprehensive Review of U.S. Spectrum Management with Broad Stakeholder Involvement Needed," GAO-03-277, January 2003, p. 6.

[35] It is important to note that the case for escalating the value of the transponders between January 1996 and the end of 2001 is different from the case for doing so for satellite radio. In this case, satellite TV was put to use more rapidly, with Dish Network reporting 6 million subscribers by the start of 2001. However, the popularity of satellite television suggests the uncertainty that was present at the time of the auction has been resolved in a favorable way.

[36] The value represented by the area under the curve would be approximately $4.5 trillion, but that is not meant to imply that the radio spectrum is worth that much money.

[37] As put forth by Ronald Coase, with minimal transaction costs – that is, less than the potential gains – and sellable property rights, an optimal, socially efficient equilibrium will tend to be achieved regardless of who owns the property rights. A classic example of the Coase Theorem involves train tracks laid in the middle of a wheat farm. As trains speed by on the tracks, sparks from the train wheels cause the wheat surrounding the tracks to catch fire. If the farmers own the property rights, they can force the train operators to install spark guards along the tracks. The operators will do so unless the costs of installing the spark guards are greater than the value of the destroyed wheat, in which case they will opt to compensate the farmers for the burnt wheat. If the train operators own the property rights, they can force the farmers to tolerate the burnt wheat. The farmers will do so unless the value of the destroyed wheat is greater than the costs of installing spark guards, in which case they will pay for the installation of the guards. No matter who owns the initial property rights, a socially efficient outcome will tend to result: spark guards will be installed or an amount of wheat will be destroyed, whichever is more efficient.

[38] To illustrate this point, consider radio broadcasting. The installed base of AM and FM radio receivers likely means that the value of those specific frequencies at an auction today would be higher than if licenses for a new radio service, such as satellite radio, were auctioned. The existing base of receivers inflate the value of any additional AM or FM license so much as to completely overwhelm other value considerations when valuing the broadcast radio band. We do not, however, take this line of reasoning to the extreme. As discussed later, we use auction values for licenses for Personal Communication Service (PCS) spectrum as representative of underlying spectrum values. This is a judgment that the mobile phone industry would expand into new bands as readily as it fills out existing bands if offered relatively unencumbered radio spectrum. Likewise, it also assumes that the installed base of mobile phones and the frequencies they use do not have the same externality as AM and FM radio services to inflate license value.

[39] This re-auction of spectrum Nextwave purchased in the mid-1990s had high bids totaling more than $16 billion—the largest single government auction in U.S. history. The licenses were in a band with established uses that needed more capacity so there was relatively little technological risk and economic uncertainty. The winning bidders were some of the largest and most sophisticated telecom companies, including Verizon and Sprint PCS. Although the licenses were not ultimately bought, for a year after the auction the winners tried to pay their winning bids, first to the FCC and then in private transactions. The average valuation from this auction of $4.18 /MHz-pop was used as the valuation point for the curve for the lower frequencies. The sophistication of the bidders and their ample time to back out of their bids, suggests that the $4.18/MHz-pop valuation from the auction was not an aberration.

[40] The average valuation from this auction of $0.0018 was used as a valuation point for the higher frequency portion of the curve. The use rules were written for a specific application, but broadband connectivity was likely the highest-valued use for this band, making the restrictions not binding and not affecting the valuation.

[41] The average valuation from this auction of $0.0012 also was used as a valuation point for the curve for the higher frequencies. Relatively few restrictions were placed on these licenses, making them representative of the underlying spectrum value.

[42] Virtually all spectrum bands below about 40 GHz have incumbents. When incumbents remain in a band they can create binding constraints on how new licensees may use their spectrum. If incumbents continue to operate in a band, then the licenses sold are unlikely to be representative of underlying spectrum values.

[43] For a license to be representative of underlying spectrum values, allowing in-band flexibility is not sufficient in and of itself. An additional requirement is that the licenses not have overly restrictive interference criterion for other (both in-band and out-of-band) uses of the radio spectrum.

[44] Several bands of spectrum allocated to specific uses were sub-divided into channels and the individual channels were then licensed. A number of auctions sold licenses to the unused channels in a given allocation. We rejected these auctions because it is often more valuable to control a block of channels than the same quantity of spectrum over scattered channels.

[45] William Safire, "Broadcast Lobby Triumphs," *The New York Times*, July 23, 1997, p. A21.

[46] Neil Hickey, "What's at Stake in the Spectrum War?; Only Billions of Dollars and the Future of Television," *Columbia Journalism Review*, Vol. XXXV, July/August, 1996, p.39.

[47] Thomas J. Sugrue, Chief of Wireless Telecommunications Bureau, FCC, Senate Communications Subcommittee, June 11, 2002.

[48] Many higher valued uses of radio spectrum require national footprints. Direct Broadcast Satellite (DBS) television service is more than proportionally valuable if it covers the entire U.S. compared to covering only a portion of the country. Primarily, this is because, on a per-person basis, it is less expensive to design mobile communications that can cover the entire country instead of just a specific region. If, in our judgment, the non-national coverage of the licenses at auction created a binding constraint on how the radio spectrum could be used, we rejected the auction as unrepresentative of underlying spectrum values.

[49] Licenses for the PCS spectrum were auctioned over several years. We used the auction closest in time to our target valuation date of December 31, 2001.

[50] Many valuable uses of the radio spectrum require minimum sized blocks to be useful. Sometimes technology requires the block to be paired and split into two blocks with a certain minimum separation between them, as is the case with most two-way mobile communications. As the frequencies change, the minimum size also varies by band – a 10 MHz block in the 2 GHz band may be sufficiently large, but unusable in the 20 GHz band. If, in our judgment, the spectrum block was too small for a given use and location, we rejected the auction valuations as unrepresentative of underlying spectrum values.

[51] If restrictions prevent the radio spectrum from being used for its highest valued use, then the auction license valuations are not representative of underlying spectrum values.

[52] If a band of spectrum simply has not been put to use as expected, we reject the auction license valuations as representative of underlying spectrum values.

[53] In December 2002 Verizon purchased unencumbered prime spectrum for approximately $1.60/MHz-pop. What accounts for the lower valuation? Clearly, reduced demand for spectrum is probably a factor. After the "telecom bubble" burst, the value of telecommunications assets generally declined. However, supply considerations may also have been a factor. In November 2002 the FCC released a major report calling for spectrum flexibility and thus a large increase in spectrum supply. The FCC also signaled that it might be willing to let the bidders on the Nextwave spectrum acquire on highly favorable terms the 190 MHz (more than six times the amount of spectrum in the Nextwave auction) previously allocated to MMDS and ITFS. This spectrum, located at 2,500-2,690 MHz, was worth tens of billions of dollars.

[54] See Amendment of Part 2 of the Commission's Rules to Allocate Spectrum below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, Including Third Generation Wireless Systems, ET Docket No. 00-258, *Notice of Proposed Rulemaking*, FCC 00-455, January 5, 2001, app. D.

[55] For in-depth examinations of the distortionary effects of taxation, see Ballard, Charles L., John B. Shoven and John Whalley, "General Equilibrium Computations of the Marginal Welfare Costs of Taxes in the United States," *American Economic Review*, Vol. 75, p. 128-138; Don Fullerton's "If Labor is Inelastic, Are Taxes Still Distorting?" *American Economic Review* Vol. 81, pp. 302-308; and Charles Stuart's "Welfare Costs per Additional Tax Dollar in the United States," *American Economic Review*, Vol. 74, p. 352-362.

[56] Gerald Faulhaber and David Farber, "Spectrum Management: Property Rights, Markets, and the Commons," presented at the 2002 Telecommunications Policy Research Conference, Alexandria, Virginia, September 2002.

[57] Spectrum Policy Task Force report, Washington DC: Federal Communications Commission, November 16, 2002.

[58] See Bennett Z. Kobb's *Wireless Spectrum Finder* for a breakdown of how U.S. spectrum is used.

[59] We believe this number to be conservative. Bernstein Research Senior Media Analyst Tom Wolzien has valued the 402 MHz of the broadcasters alone at $367 billion (Tom Wolzien, "Whose Bandwidth is it Anyway?" Speech at the National Association of Broadcasters Futures Summit, Monterey, California, March 25, 2001); Brookings Institution Senior Fellow Robert W. Crandall has estimated the value of 1 Gigahertz or prime spectrum at $300 billion (Robert W. Crandall, "New Zealand Spectrum Policy: A Model for the United States? *Journal of Law and Economics*, Vol. 41, 1998, pp. 821-840); and NTIA Deputy Assistant Secretary Michael D. Gallagher has informally estimated the value of the entire spectrum at $2 trillion (speech at Progress and Freedom Foundation conference, "When Wireless Grows Up," Rayburn House Office Building, Washington, DC, July 12, 2002).

Part 2

[60] Communications Act of 1934, Title III, Section 301.

[61] See the New America Foundation's Fact Sheet, "The Private Use of Public Assets: Examples of Auction and Lease Fees Paid on Public Resources," September 9, 2002.

[62] An overview of how government spectrum is used can be found on the NTIA Office of Spectrum Management web page. Link: http://www.ntia.doc.gov/osmhome/roosa2.html.

[63] A database of frequency allocations was compiled from the FCC allocation database, then sorted and summed by licensee type. Of the 299,999.991 MHz of spectrum from 9 kHz to 300 GHz, a total of 282,640.5535 MHz is allocated to "Federal Government" and "Shared" licensees.
For more information, see the FCC Radio Spectrum Home Page, Office of Engineering Technology, http://www.fcc.gov/oet/spectrum/.

[64] From the FCC allocation database. Of the 251,800 MHz of spectrum from 48.2 GHz to 300 GHz, a total of 247,300 MHz is allocated to "Shared" licensees. For more information, see the FCC Radio Spectrum Home Page, Office of Engineering Technology, http://www.fcc.gov/oet/spectrum/.

[65] Senator Conrad Burns, Senate Commerce Committee, Hearing on "Spectrum Management: Improving Management of Government and Commercial Spectrum Domestically and Internationally," June 11, 2002.

[66] Senator Larry Pressler, Former Chair, Senate Commerce Committee, Serial #104-635, p. 2.

[67] William Kennard, Former Chair, FCC, February 2000, cited in speech by Dale N. Hatfield, Chief, Office of Engineering and Technology, FCC, June 20, 2000. An abbreviated version is cited in *Forbes* magazine, November 2002.

[68] Susan Ness, former FCC Commissioner, "Blueprint for Spectrum Management," Speech before PCIA's PCS '98, September 23, 1998.

[69] David Wye, Chief of Spectrum Policy, AT&T Wireless, cited in "Dead Air," *Forbes*, November 11, 2002, p. 138.

[70] Thomas Hazlett, "Spectrum Flash Dance: Eli Noam's Proposal for 'Open Access' to Radio Waves," *Journal of Law and Economics*, Vol. XLI, October 1998, p. 816.

[71] The NTIA has an in-depth Frequency Masterfile Database on compact disc, but refuses to release it to the concerned public.

[72] See the transcripts of the Federal Communications Commission Spectrum Policy Task Force panel workshops, August 1st, 2002 to August 9th, 2002.

[73] Current as of September 1st, 2002.
Link: http://www.wow-com.com.

[74] Research conducted by In-Stat/MDR, August, 2002. Courteously supplied by Gemma Paulo. See also Allied Business Intelligence, "Wi-Fi IC Shipments Set To Top Expectations," December 18, 2002,
http://www.alliedworld.com/pdfs/wlic03pr.pdf.

[75] The analog/digital classifications are based on general observations and not on detailed evaluations of the systems used in every band. Both analog and digital technologies are found throughout the utilized spectrum. The analog/digital frontier marks the border in the radio spectrum between bands dominated by older analog technologies (less than 1 GHz) and new digital technologies (more than 1 GHz). Many bands share a mix of analog and digital services. Bands less than 1 GHz considered predominantly analog include aviation and maritime, personal radio (Part 95), amateur radio, cordless phones around 40 MHz, broadcast radio and TV, and private and public mobile radio below 512 MHz.

[76] General Accounting Office, GAO-02-906, "Better Coordination and Enhanced Accountability Needed to Improve Spectrum Management," September 2002, p. 3.

[77] Michael Behar, "The Broadband Militia," *Washington Monthly*, March 2002, p. 33.

[78] Thomas Hazlett, American Enterprise Institute, Senate Committee on Commerce, Science, and Transportation, Hearing on the Transition to Digital Television Broadcasting, March 1, 2001.

[79] David Ho, "FCC Chairman Proposes Overhaul of Policy on Airwaves," The Associated Press, October 30, 2002.

[80] Cited in Stephen Labaton, "FCC to Promote a Trading System to Sell Airwaves," *The New York Times*, March 13, 2000, p. A1.

[81] Senator Ron Wyden, Senate Communications Subcommittee (D-OR), Hearing on June 11, 2002.

[82] Comments of CEA in FCC Docket No. 02-135, dated September 30, 2002.

[83] GPS is not licensed or unlicensed. It is a government service to the public that is freely available to all and can be incorporated in any manufacturer's product without a special license from the U.S. government. Its location and time information is one of America's great information commons. Effective use of GPS could also revolutionize unlicensed spectrum management. For example, the allowable geographic coverage of unlicensed devices could be determined on the fly based on a GPS determined location. The more rural and sparsely populated an area is, the greater its allowable geographic coverage could be.

[84] For in-depth discussions about the technical parameters, expected services, growth and inhibiting factors of Third Generation mobile telephony, see "3G Mobile Licensing Policy: From GSM to IMT-2000" and "The UMTS Forum – Shaping the Mobile Future." Links: http://www.itu.int/osg/spu/ni/3G/casestudies/GSM-FINAL.pdf; and http://www.umtsforum.org/brochures/UMTS.pdf, respectively.

[85] For an extended discussion of these ideas, see Keven Werbach, "Open Spectrum: The New Wireless Paradigm," Washington, DC: The New America Foundation, October 2002.

[86] Remarks of Michael K. Powell, Chairman of the FCC, "Broadband Migration III: New Directions in Wireless Policy," October 30, 2002.

[87] Statement of FCC Commissioner Kathleen Q. Abernathy regarding *Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3GHz Band, Notice of Inquiry*, FCC 02-328, ET Docket No.02-380, December 11, 2002, p. 15.

[88] Statement of FCC Commissioner Michael J. Copps regarding *Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3GHz Band, Notice of Inquiry*, FCC 02-328, ET Docket No.02-380, December 11, 2002, p. 16.

[89] Statement of FCC Commissioner Kevin J. Martin regarding *Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3GHz Band, Notice of Inquiry*, FCC 02-328, ET Docket No.02-380, December 11, 2002, p. 17.

[90] This feature of smart radio is often called "software defined radio" or "agile radio."

[91] At recent auction prices (Auction #35), the total value of the less than 200 MHz used for mobile communications is greater than $220 billion. In an auction dating back to mid-1994 (Auction #2), winning bids for 1 MHz of spectrum, 1/300,000th of the radio spectrum, totaled $213,892,375.

[92] For a discussion of the difficulties of coming up with an efficiency metric, see "Report of the Spectrum Efficiency Working Group," Federal Communications Commission, ET Docket No. 02-135, November 15, 2002.

[93] A measure of spectral efficiency, Channels per MHz, is defined as the number of channels divided by the number of MHz used to deliver those channels. Television markets are not homogenous across the United States: Some markets receive more channels; some receive less. The average U.S. TV market receives just seven over-the-air television channels. Due to the disproportionate population sizes of New York and Los Angeles, the average American receives approximately 13 over-the-air television channels. Our efficiency calculation uses this latter, population-weighted, number of channels. Coupled with our decision to attribute only 402 MHz for television broadcasting (ignoring the more than 3 gigahertz of higher frequency spectrum allocated for industrial broadcasting purposes), our efficiency calculation is quite generous to over-the-air broadcasters. Nonetheless, current over-the-air broadcasting still yields just 0.03 Channels/MHz.

In the future, broadcasters are supposed to vacate 108 MHz (TV channels 52-69) of their consumer spectrum with the adoption of digital technologies. When this transition is complete, over-the-air broadcasting will continue to use at least 294 MHz for consumer delivery. Utilizing the increased capabilities of digital technology, broadcasters should be able to provide four digital channels in place of each analog channel. Theoretically, this implies an average, population-weighted, number of channels of 52 [13 analog channels multiplied by digital scalar of 4]. Even after a successful digital television transition, over-the-air broadcasting will have an efficiency measure of 0.18 Channels/MHz. For a discussion of the efficiency with which broadcasters use the airwaves, see Thomas Hazlett's "The Wireless Craze," Washington, DC: American Enterprise Institute. http://www.manhattan-institute.org/hazlett/working_01_02.pdf.

[94] Current satellite technology allows for eight unique orbital positions, three of which are able to provide coverage to the entire United States. Each orbital position contains 32 satellite transponders. According to the Satellite Broadcasting and Communications Association, each transponder can support up to twelve standard-definition television channels, thus yielding 384 channels per orbital slot. Using 384 channels and 900 MHz for satellite television produces an efficiency calculation of 0.43 Channels/MHz, more than 14 times more efficient than existing over-the-air television. Even with a fully successful digital transition, satellite television will still use spectrum more than twice as efficiently as existing broadcasters.

[95] According to BIA Research, the average number of FM radio channels per market is 13.5. FM radio broadcasters are allocated 20 MHz (88-108 MHz) for consumer delivery, yielding an efficiency calculation of 0.675 Channels/MHz. Allocated 25 MHz of spectrum (2320-2345 MHz), satellite radio providers deliver 100 unique channels, or 4.0 Channels/MHz. See Hazlett's *The Wireless Craze* and XM radio's website: http://www.xmradio.com and http://www.sirius.com.

[96] Thomas Hazlett, "The U.S. Digital TV Transition: Time to Toss the Negroponte Switch," Washington, DC: American Enterprise Institute. Link: http://www.aei.brookings.org/publications/working/working_01_15.pdf.

[97] According to the Code of Federal Regulations Rule 47 Part 74.602, auxiliary television broadcasting is permitted in various regions totaling 3773.5 MHz of the radio spectrum. There is a noteworthy discrepancy between the Federal Code and the National Association of Broadcasters (NAB) "Radio and Television Broadcasting Spectrum Usage" chart, dated 1996. This chart lists 6205.65 MHz of spectrum used for auxiliary radio and television broadcasting. At least some of this difference can be attributed to broadcasters' use of bands ruled for Satellite Communications (Rule Part 25) for auxiliary broadcasting, which is depicted on the NAB's chart but not in Part 74 of the Code of Federal Regulations. The figure from the Code of Federal Regulations refers only to bands ruled for television Auxiliary Broadcasting (Rule Part 74). According to NAB's librarian, this 1996 poster is the latest detailed chart of radio and television broadcast spectrum usage contained in the NAB library. Numerous calls were made to NAB engineers to gather information about broadcaster usage and sharing of auxiliary spectrum as well as to explain the discrepancy between the NAB chart and FCC regulations. No clarifying information was provided, except to refer us back to the federal code.

[98] E.g., see J.H. Snider, "The Paradox of News Bias: How Local Broadcasters Influence Information Policy," in *Politics, Discourse, and American Society*, edited by Roderick P. Hart and Bartholomew H. Sparrow, New York: Rowman & Littlefield, 2001.

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

[100] The State of Maryland outfitted 6,700 public employees with commercial mobile telephones in 2002, spending at least $5.3 million. Report of the Maryland Department of Legislative Services, February 2002, cited in *The Capital*, February 22, 2002, p. A8.

[101] Scott Woolley, "Dead Air," *Forbes*, November 11, 2002.

[102] When it does happen, it may end up on the front page of *The New York Times*. The Army Corps of Engineers manages 11.7 million acres of federal land. Its real estate regulations require that "when federally owned property is leased or sold, fair market value should be obtained." See Douglas Jehl, "How to Lease Land from Government and Not Pay Rent," *New York Times*, March 13, 2003, p. A1.

[103] Mark Lewyn, "Airwave Wars," *Business Week*, July 23, 2002.

[104] George Gilder, "Auctioning the Airwaves," *Forbes* ASAP, April 11, 1994, p. 99.

[105] This analogy comes from Timothy Shepard. Comments on FCC ET Docket No. 02-135, "In the Matter of Spectrum Policy Task Force Seeks Public Comment on Issues Related to Commission's Spectrum Policies," July 8, 2002.

[106] In practice, this is usually described as interfering with another audience member's ability to hear the announcer. But, in fact, the primary concern is with the speaker's guaranteed ability to reach an audience. For if the concern was with the audience, the option would be given to the audience member, not the announcer, whether to listen to the announcer or an adjacent person. For a recent example, see H.R. 4560, the Auction Reform Act of 2002.

[107] Eli Noam, "Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism." *Journal of Law and Economics*, Vol. XLI (October 1998), p. 765.

[108] Kevin Kahn, Intel Corporation, Senate Commerce Committee, Hearing on the Future of Spectrum Policy, March 6, 2003.

[109] Senator Ron Wyden, Senate Communications Subcommittee, June 11, 2002.

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