The Airwaves Explained

A spectrum of possibilities.

BY NEIL CARLSON

For all the benefits it offers, rapidly advancing technology may leave even a well-educated public in the dark about matters that bear directly on their lives. These days, that's the issue with the science of wireless communication, which is moving fast to transform the ways people receive news and entertainment and communicate with each other.

Most people don't spend much time thinking about "smart radio" or "collaborative gain networks," yet these and other marvels of new electronics are forcing decisions on reform of federal communications policy that will dictate the shape and substance of democracy, politics and economics in the 21st century. How has this policy evolved, and what does the new technology portend for its future?

The corporate leaders, policy experts and public interest advocates who spend their days thinking about the issue agree that the current system of allocating space for devices that make use of the electromagnetic spectrum is not working. Understanding why requires a bit of history and a short physics lesson.

The "airwaves" used for a growing body of communication—radio, television, cell phones, CB radio, pagers, cordless phones, garage door openers—consist of electromagnetic waves that are part of the larger electromagnetic spectrum, which includes light, ultraviolet and other forms of radiation.

The section of the spectrum useful for broadcasting is defined by a range of frequencies—the rates at which waves oscillate—measured in megahertz. A transmitting device generates electronic impulses that travel as waves of a certain frequency within this part of the spectrum. A receiver must be tuned to the same frequency to capture them.

Through most of the last century, much of radio, television and other wireless communication depended on "analog" broadcasting of sounds, images or other data by altering or "modulating" the shape or other aspects of electromagnetic waves. Analog radios, TV sets and other devices receive modulated waves by tuning to their frequencies and converting them to images, sounds or commands—to beep a beeper or open a garage door, for example.

Advances in digital communications technology over the last decade threaten to render all of this obsolete. It is now possible to convert sounds, images and other data into electronic impulses that may be processed by computer chips. In this form, they can be transmitted and received via frequencies of the spectrum in greater volume, and with much more efficiency and precision than as analog waves.

Digitization also makes possible an intimate marriage of broadcasting and computer networking, locally and globally on the Internet. In theory, this will one day grant individuals great freedom to customize communications to suit their needs and tastes—and to do so in infinite variety. As one person archives a complete file of "The Sopranos" to watch at will, stores MP3's of favorite music and subscribes to Internet-based news services, her neighbor creates a database from the food channel and samples TV shows from India, South Africa and Los Angeles.

Realizing such a vision, however, depends on a lot: continued advances in digital communications with no unforeseen snags, and a massive shift of software and hardware on behalf of everyone who wants to broadcast and receive.

The need for government to regulate use of the spectrum arose from the fact that analog technologies are susceptible to interference: If there is another transmission on the same frequency, the receiver gets confused.

The current regulatory regime took shape in 1934, when the Federal Communications Act created the Federal Communications Commission and charged it with allocating spectrum. Individuals or companies wanting to use a slice of the spectrum apply for an F.C.C. license, which authorizes the holder to use a particular frequency for a specific purpose in a particular location. (Thus, an ABC affiliate in Indianapolis, say, is licensed to broadcast "The Bachelor" and other shows at a certain frequency and power level, but it may not use its spectrum allocation for radio or cellular communications.) Over the following 70 years, the F.C.C. treated the spectrum the way a city zoning board treats real estate, setting aside different areas for different uses—broadcast television and radio, cellular phones, fixed satellite communications, military and federal government communications—and granting free, renewable licenses to spectrum users. The F.C.C. retained huge patches of unallocated "white space" between broadcast frequencies to avoid interference. It also set aside a relatively small portion of spectrum for unlicensed uses such as amateur radio, walkie talkies, global positioning satellite devices and wireless networking.

Although the rationale behind this allocation process made sense in the early 20th century, it had two unintended consequences. First, in granting free, exclusive licenses to the public airwaves, the F.C.C. was essentially sponsoring what the New America Foundation and others consider the huge gift of a public asset to private business. Second, by the mid-1990's, new communications technologies created huge demand for spectrum, but there was little left to allocate. And incumbent license holders, notably the radio and television broadcast industries and cellular communications companies, have no desire to give up their valuable spectrum allocations. (Legally, of course, "their" spectrum belongs to the public, but the F.C.C. has never terminated an industry's spectrum allocation without compensation.)

Meanwhile, digital communications have revolutionized use of the spectrum. Small, low-cost computer chips mean that wireless devices are more sophisticated in how they "listen" to the spectrum, how they

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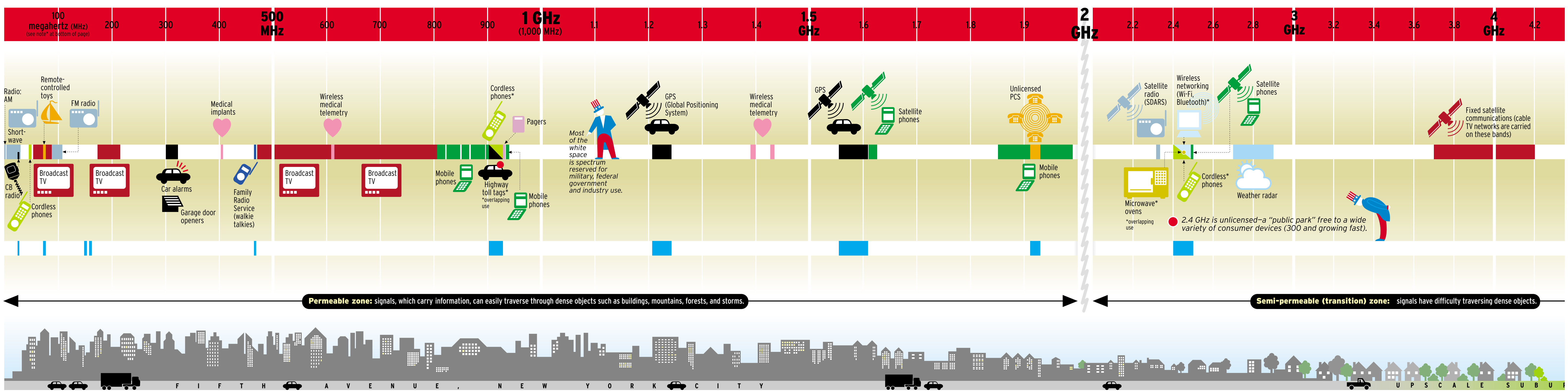
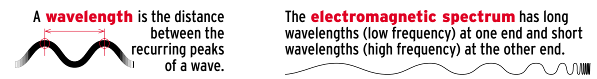


* Radio waves are transmitted at different frequencies measured in **hertz (Hz)**. A slice of spectrum contains a band of frequencies. The wider the band, the more information carrying capacity it has. (It has more "bandwidth").

Wireless bandwidth is generally counted in megahertz.

Abbreviations: **kilohertz** (1,000 hertz) is written as **kHz**,
megahertz (1 million hertz) is written as **MHz**, and
gigahertz (1 billion hertz, or 1,000 megahertz) is written as **GHz**.

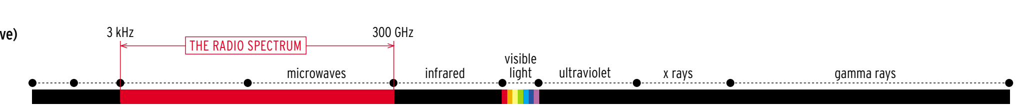


A **wavelength** is the distance between the recurring peaks of a wave.

The **electromagnetic spectrum** has long wavelengths (low frequency) at one end and short wavelengths (high frequency) at the other end.

The size of the wavelength influences the ability of a wave to pass through objects. Generally, as a wavelength decreases in size, its value also decreases.

The **radio spectrum** (enlarged in the charts above) is the portion of the total electromagnetic spectrum distinguished by its value for communication.



The amount of spectrum required for everyday communications

Today, most wireless communication is low fidelity audio. In the future, high fidelity video could require up to 5,000 times as much bandwidth.

decode transmissions, and how they reassemble broken or incomplete packets of data. Frequencies that once carried a single analog signal, for example, can now carry 10 signals. And with digital transmission, there is no need to set aside so much white space between frequencies.

The challenge now is to reform federal spectrum policy so it reflects this new reality. Last summer, Michael Powell, chairman of the F.C.C., assembled a Spectrum Policy Task Force and charged it with creating a blueprint for reform. As the task force got down to work, nearly everyone called to testify agreed that the F.C.C. should do away with the grossly inefficient licensing regime. And most experts also agree that in doing so, the F.C.C. should do away with onerous restrictions on use. Beyond that, the advocates of spectrum reform fall roughly into three categories: those who favor a "commons" approach, those who favor a "property rights" system and those who want a middle way between the two.

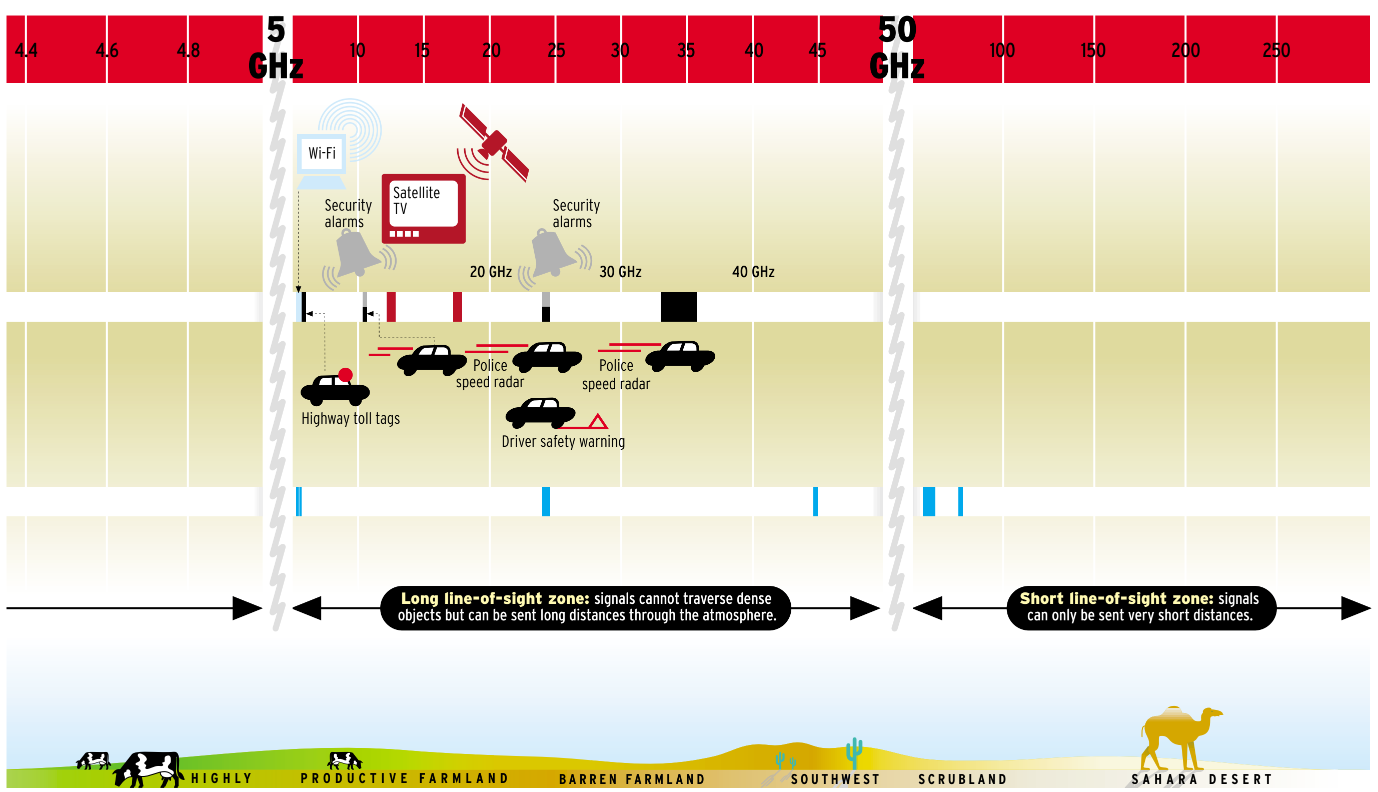
Commons

Advocates of open spectrum, or a commons approach to the airwaves, argue that new technologies—some already commercially available, some coming in the near future—will effectively create unlimited spectrum capacity. The best long-term approach to spectrum policy, they argue, is to set some basic rules of the road but then to let anyone and everyone use the spectrum as they see fit. In this model, the technology embedded in individual devices—a laptop computer, a mobile phone, a home wireless network—would provide capacity for wireless communications. Instead of buying access to privately owned communications infrastructure, citizens and consumers would create ad hoc networks that were in and of themselves the wireless communication infrastructure.

New technologies such as smart radio, ultra-wideband, and collaborative-gain networking make the spectrum commons possible (see opposite page). The commons infrastructure has more in common with the Internet, which is essentially a diffuse network of users who all use a set of standard protocols to talk to each other. Just as no one "owns" the Internet, no one would own the airwaves. Like the Internet, the capacity of the commons increases at the edges, through smarter gadgets, sophisticated software and better transmitters and receivers.

Promoters of the commons approach include public interest groups like Consumers Union, as well as leading legal scholars like Lawrence Lessig, a professor at Stanford University Law School and Yochai Benkler, a professor at Yale Law School. All recognize, furthermore, that it may take some time and financial investment to accomplish a wholesale shift to a communications system based entirely on such networks.

The politics of the commons is a peculiar combination of libertarian technologists, progressive academics, consumer advocates, and corporate interests. Computer makers, software developers and consumer communication device manufacturers all have a vested interest in creating the next generation of smart radios and wireless communications devices. Meanwhile, consumer groups, public interest advocates, and progressive intellectuals like the idea of the commons, and in equal measure, distrust the consolidation of corporate power embodied in the property rights model.



LOW FIDELITY COMMUNICATIONS ↕ HIGH FIDELITY COMMUNICATIONS (APPROXIMATELY)

- 10 kHz .... Voice (e.g., telephone quality)
- 100 kHz .... Music (e.g., CD quality)
- 1,000 kHz (=1 MHz) .... Standard definition TV (e.g., VCR quality)
- 5,000 kHz (=5 MHz) .... High definition TV (e.g., movie theater quality)
- 50,000 kHz (=50 MHz) .... Super high definition TV* (e.g., glossy magazine quality)

*Super high definition video in 3D or holography would require additional bandwidth.

"The basic problem is that demand for spectrum is outstripping the supply."
U.S. General Accounting Office Report, September 2002

"[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

Property Rights

In this view, the best way to handle the spectrum is to privatize it and sell it off like property. Advocates of privatization argue that doing away with the F.C.C.'s current system of licensing and use restrictions would allow the market to determine the most efficient uses of spectrum. Spectrum would become property, and owners could use their slice of spectrum however they pleased—they could broadcast on it, use it for cellular phones, or sell unused spectrum to the highest bidder. Advocates of property rights argue that new technologies are unproven, and that if they fail to deliver on the promise of endless capacity, the common airwaves would become a crowded cacophony—and an economic and policy disaster.

Property rights advocates tend to be skeptical of technology's ability to meet all the demands—current and future—for spectrum. And if spectrum is a scarce resource, free markets lead to the best and most efficient use of those resources. In the short term, a property rights system tends to favor existing technologies (radio and television broadcasting, cellular phones), but the underlying market rationality, advocates say, would foster innovation as new technologies replaced older ones. Even if spectrum scarcity is no longer an issue in the future, advocates argue, a property rights framework would allow companies to capitalize the costs of innovation as new technologies emerge and would effectively allocate spectrum in the interim.

Incumbent corporate interests favor property rights, as do free-market economists (such as the American Enterprise Institute's J. Gregory Sidak) and legal theorists such as Gerald R. Faulhaber and David Farber, co-directors of the Penn Initiative for Markets, Technology and Policy at the University of Pennsylvania. Broadcasters in particular are lobbying for a property rights approach since they would be well positioned to acquire valuable spectrum. Some advocates have even suggested giving away property rights to current licensees—a policy that would effectively grant a $771 billion windfall to incumbent corporate interests. In a sign that the F.C.C. may be leaning in this direction, a recent ruling allows current licensees to lease unused portions of their spectrum allocation for alternate uses.

The Middle Way

Most argue for splitting the difference between the property rights and commons models. They say that the commons approach is preferable both as an economic model and as an appropriate use of a valuable public resource—but the technology needs time to develop. In the interim, middle way advocates argue that F.C.C. policy should retain public ownership over the spectrum while pursuing two core goals: freeing as much spectrum as possible for the commons and doing away with use restrictions on existing licenses. For example, the New America Foundation has urged the F.C.C. to "lease" spectrum to commercial interests. In exchange for complete flexibility during the term of the lease (lessees would be free to sublease, barter, trade and consume spectrum however they wished), the lessee would make annual payments. As technology developed, the F.C.C. could reallocate the spectrum covered under expiring leases to the commons.

In addition, these advocates argue for more unlicensed spectrum space—essentially more commons. They also argue that the spectrum policy should generally move toward the commons, freeing up even more spectrum as the underlying commons technology becomes commercially viable.

Other advocates of the middle way, including some who lean toward the commons or property rights model, share a belief in the importance of blending the two opposing approaches for the time being. Michael Powell, chairman of the F.C.C., seems to be a middle-way believer, although it remains to be seen whether F.C.C. policy will follow this path. ■

The Architecture of the Airwaves

Conventional wireless technologies are pretty sorry when it comes to using the radio spectrum efficiently. Analog technologies such as broadcast television and radio and analog wireless telephones use up enormous amounts of spectrum. But as the New America Foundation has noted in "The Citizen's Guide to the Airwaves," excerpted on these pages, new digital technologies like data compression (eliminating redundant information), packet switching (using empty spaces in the spectrum) and new modulation schemes (placing more data in a single burst of energy), are capable of using the airwaves more efficiently than ever before.

Here are three key technologies:

Smart Radio. Smart radio is a generic term for a device that listens to a frequency before it transmits its signals. If it hears that a frequency is busy, it switches to another. If that is busy, too, it tries another, and so on until it finds an open frequency. Software programs determine how the device navigates among frequencies. The upshot is that "radio" devices—radios, televisions, wireless phones, pagers, wireless computer networks—can jump frequencies together, using spectrum efficiently without interruption.

Ultra Wideband Radio. Ultra-wideband (UWB) radio uses numerous low-power transmissions across a number of frequencies. To conventional devices, these transmissions appear as radio background noise, but to a sophisticated, sensitive receiver, these wideband transmissions are recognizable data. The receiver picks up the spread signals, reassembles them, and translates them into a usable end product—a voice transmission, a document or a digital image. Using UWB, I could send my brother a digital photo over the same frequency NBC was using to broadcast "Friends," yet no one between New York and Minneapolis would be the wiser.

Collaborative Gain Networks. The Holy Grail of wireless technologies, collaborative gain networks add capacity with each user on the network. Imagine me tapping away on my laptop at the kitchen table. Across the street, my neighbor is searching for an airfare on the Internet. Two blocks away, someone else is listening to archived editions of "This American Life" on Internet radio. Now imagine that our computers are all broadcasting and receiving at the same time: instead of transmitting and receiving through a cable modem, we are all broadcasting and receiving through each other's computers. The more people there are on the network, the more powerful it is. If one person's computer crashes, wireless communication simply gets routed elsewhere in a diffuse, seamless network. —*N.C.*