Beyond WiFi : Open Spectrum

ロバートJ. バーガー
（GLOCOM客員研究員）

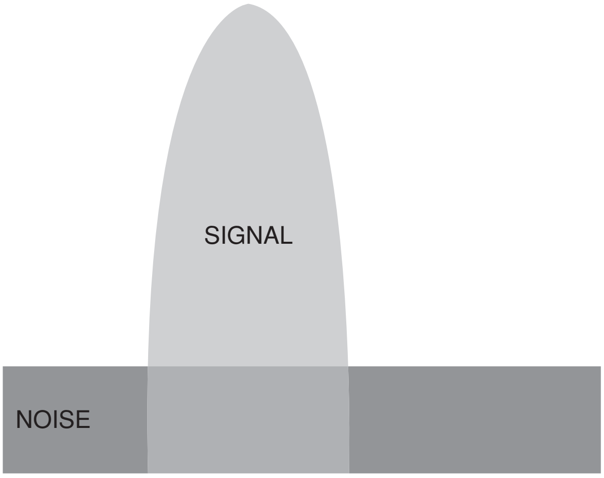
Radio Spectrum technology and regulatory policy is in the midst of a revolution. The use of unlicensed known, as "Open Spectrum" is poised to be the next wave of disruptive technologies that will continue the Internet's march to integrate and facilitate all electronic communications with open standards and commodity hardware. Open Spectrum is a collection of new radio technologies and a techno-political movement. WiFi (technically IEEE 802.11 standard) wireless LAN has demonstrated the innovation that can be unleashed with unlicensed spectrum. Products and services based on the 802.11b standard created a US$2.9B industry in 2002. Open Spectrum calls for opening up most of the spectrum for unlicensed use in ways that can co-exist with legacy spectrum users "creating" huge new capacity with existing spectrum. These new technologies and the grass roots support behind them may be what is needed to break the last mile bottleneck. Open Spectrum will help to manifest nearly ubiquitous Internet access to an extent previously thought to be only available in the dreams of science fiction.

From Science Fiction to Ubiquity

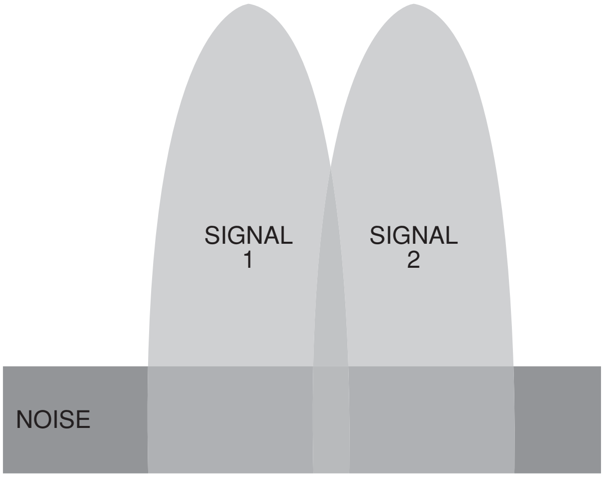
At first glance, the promise of Open Spectrum does sound like the stuff of science fiction. Being able to have millions of people simultaneously utilize their surrounding spectrum and each have 10Mbps, 100Mbs or even gigabits / second of bandwidth where in the past it was difficult to have enough spectrum for a handful of TV stations, scores of radio stations and a few cell phone carriers seems like an absurd dream. This is because our "common sense" understanding of radio spectrum capacity comes from our day-to-day experience with radio technologies that have been largely unchanged since the beginning of the last century. Back when radio was first being developed and regulations were being set in stone, radio technology was incredibly primitive. Radio (and later TV) receivers can only cope with one signal at a time and that signal must be much "louder" (i.e. Higher amplitude) than the noise floor and any other signal that is near the same frequency.

Such a dumb receiver can be easily confused if there is a signal at or near the same frequency and whose amplitude approaches or exceeds the amplitude of the signal that the dumb receiver is trying to listen to. This is what is generally called "interference". However, you can see that the problem isn't interference between the signals, but the inability of the receiver to differentiate between the signal it is interested in and the other unrelated signal.

In the late 1920's and early 1930's, this kind of simple circuitry was all that was possible. Therefore, the radio industry came up with a regulatory approach to make sure that there can only be one signal allowed in



Legacy Radio Signal: Receiver treats high power radiation as signal
(Signal is much greater than noise level)



Overlapping signal seen as "interference" to legacy receiver. Traditionally solved by exclusive licensing

each carrier frequency that is assigned to each station in a geographical area. Only one entity, the station licensee, can transmit that signal.

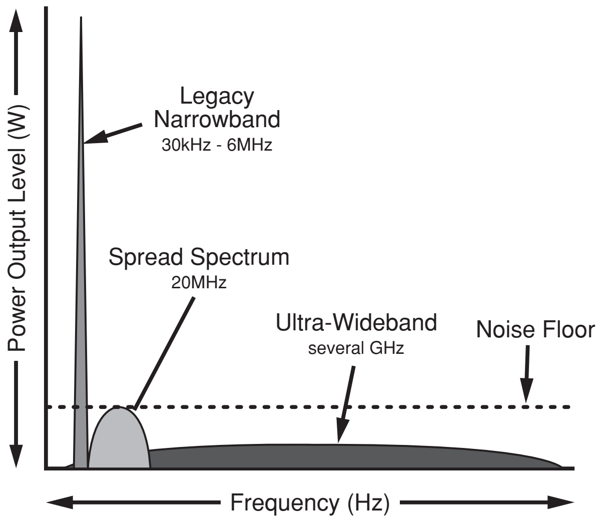
These analog circuits are so dumb, that you cannot have another signal even near the signal of the allocated channel. Guard bands of unused frequencies (extra channels!) are required between channels in each geographic region, wasting even more spectrum. That is why there are hardly ever two adjacent TV or Radio channels in one city. The government under the guidance of industry applied a regulatory "patch" to what really is a technological problem.

This has been going on for so long that it has led people to believe that this is the natural and only way to think of spectrum and interference. That spectrum must be carved up into a limited number of small channels with a regulatory or property model to protect receivers from interference from other devices.

Today with the ability to inexpensively make chips with millions of transistors, with new modulation techniques and better understanding of information theory, we can embed a huge amount of signal processing into transmitters and receivers, allowing them to discern the signal they are interested from potentially millions of other signals and noise. They can operate at much lower power and share spectrum through multiple dimensions of coding, frequency agility, and spatial /temporal reuse compared to the traditional single dimension of a frequency channel.

Moore's Law: Power for dynamic and intelligent radios

Open Spectrum technologies take advantage of Moore's Law and its associated inexpensive signal processing and embedded intelligence power to extract huge "new" capacity from spectrum. The techniques can be split into two major categories; Physical layer access methods such as Wideband Spread Spectrum and intelligent ways of utilizing the spectrum which can include cognitive radios and mesh networks.



Legacy Narrowband vs. 802.11 Spread Spectrum vs. Ultra-wideband (not to scale)

Wideband Spread Spectrum Physical Layer

The primary physical layer techniques are various wideband spread spectrum techniques such as Ultra-Wideband (UWB). There are already many products that use some form of spread spectrum including 802.11. However, the current products have very limited amounts of spectrum allocated to them. For instance, 802.11b/g has 75MHz - 85MHz (depending on which country) and 802.11a has about 300MHz (again more or less depending on different countries' spectrum policies). Wideband spread spectrum such as UWB spread their signal over gigahertz of spectrum but it utilizes only a tiny amount (pico-watts!) of power per hertz. This means that an UWB signal "looks" like background radiation (known as the noise floor) to conventional narrowband radio receivers.

Wideband Spread Spectrum receivers do not "tune in" on signals. Instead, they use digital processing techniques such as code and/or timing synchronization. Embedded digital codes in the data or the timing of the digital signals allows the receiver to extract the desired signal out of the noise floor. Thus, it is possible to have a huge number of simultaneous signals overlaying each other across the spectrum. The number and the bandwidth available is only limited by the processing power in the devices communicating and in the amount of spectrum that can be spread across. This is known as Process Gain from Claude Shannon's Communications Theorem. Shannon's Theorem combined with Moore's Law (digital processing power doubles every 2 years) clearly demands that we need to have spectrum policy that allows the radios to spread across as much spectrum as possible if we want to utilize spectrum to its fullest capacity.

UWB is particularly appropriate for low power, relatively short distance applications such as Personal, Local and possibly Neighborhood Area Networks (1 - 100 meter ranges). When UWB and other wideband spread spectrum techniques are allowed to operate starting at 100's of MHz through 10 GHz, it is possible for the signal to pass through walls and other obstructions even at low power. Current US regulations require UWB to operate above 3.1GHz and very low power levels so they cannot generally penetrate walls. Some of these issues can be transcended using the cognitive radio and mesh network techniques described later. It is also expected that over time, wideband spread spectrum will be able to operate across the spectrum and in some situations/spectrum at higher power.

Cognitive and software defined radio for more intelligent spectrum utilization

Existing spectrum policy forces spectrum to behave like a fragmented disk. It chops up the spectrum into thousands of small bands. Not only does this fragmentation make it difficult to take full advantage of spread spectrum, but it just plain wastes the spectrum. Recent measurements by the FCC in the US has shown that even in a major urban areas, only 30% of the allocated spectrum was being utilized at any one time.

This leads to the second type of Open Spectrum technique; Cognitive radios also known as agile or software defined radios. Cognitive radios have embedded intelligence and RF technology that allows them to know what kind of transmissions are desired (bandwidth, latency, urgency) and can "listen" to huge swaths of spectrum and determine which chunks of spectrum are available around them. They also know rules of what spectrum could potentially be shared if a primary licensee of that spectrum is not using it at that time or place where the cognitive radio is located. The cognitive radio could then utilize those chunks of spectrum that are available at that time and place to talk to other cognitive radios nearby using the most appropriate RF modulation techniques for the desired transmission and available spectrum. A software defined radio can transmit / receive customized RF modulations which can be conventional, ultra-wideband or even multi-band where spread spectrum techniques can be spread across many non-adjacent bands instead of continuous spectrum that single band UWB requires.

The intelligent sensing and dynamic access capabilities of cognitive radios will allow them to operate at power levels higher than the lowest common denominator noise floor since they "know" they aren't interfering with any other transmitters in the area near them, thus allowing them to co-exist with legacy radio applications. An immediate example of this would be the common situation where there are whole television channels that are not allocated in a city because they are near an allocated channel in frequency. For instance, TV channel 4 may be allocated for Tokyo, but there will be no Channel 3 or 5 there because TV receivers have traditionally not been able to cope with adjacent channels. However, a cognitive radio could use those frequencies at power lower than television but higher than the noise floor and not cause problems with all but the most ancient of televisions.

Mesh Networks leverages intelligence and geographical spectrum reuse

Embedded intelligence will also allow each Open Spectrum device to potentially be not only an end node in a network, but also a relay unit for any near by neighbors forming a mesh network instead of a conventional point to point or point to multipoint architecture. Such a mesh network would mean that as long as one or more nodes can access a gateway to the backbone, any node that can connect to any other node of the mesh could get their data to and from the backbone as well. The neighbor-to-neighbor links can thus be very short; in the range of UWB and other low power spread spectrum techniques. The more devices that participate in the mesh, the more possible paths there are to the backbone (and to each other). Another interesting aspect of such a mesh network is that the capacity of the mesh increases as more nodes are added! This is known as Cooperation Gain. Assuming that there is a critical mass of nodes and backbone gateways so that new nodes have a path to the backbone, the system scales very nicely and allows for lower power output per node and thus dramatic geographical spectrum reuse while still extending the coverage area of the mesh.

This article gives a glimpse of the possibilities that are offered by Open Spectrum. These technologies are mostly at the lab stage right now. Chipsets for UWB are due out this quarter and primitive first generation devices should be available later this year. There is still significant work to be done to develop the standards, software and hardware to bring the vision to fulfillment. It is also critical to ensure that the policy and regulatory environments do not stifle this promising set of technologies. The opportunities to be an innovative leader in this new market are wide open. The nations and companies that jump in now can be the leaders of this next generation of communications technology.

More information can be found at:

Greater Democracy
An Open Spectrum FAQ
by David Weinberger Jock Gill, Dewayne Hendricks, and David P. Reed:
http://www.greaterdemocracy.org/OpenSpectrumFAQ.html

Greater Democracy
Why Open Spectrum Matters: The End of the Broadcast Nation
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http://www.greaterdemocracy.org/framing_openspectrum.html

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Some Economics of Wireless Communications
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A good overview of UWB:
Scientific American May 2002 Issue:
Wireless Data Blaster by David G. Leeper
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