

# **U.S. Radio Spectrum Policy: A Political and Technological Perspective**

Kathleen Young  
The University of South Carolina  
2003 WISE Intern  
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## **About the Author**

Kathleen Deborah Young is a second semester senior at the University of South Carolina. She also has a minor in Japanese and hopes to further extend her cultural horizons through extensive traveling post-graduation. Her hometown is Charleston, South Carolina where her abundant family resides, and where she too hopes to make her home again one day. Her other future plans include graduate school and working to make the world a better place.

## **About the WISE Program**

The WISE program provides an opportunity for top engineering students to learn about the engineer's role in public policy. The students spend 10 weeks of the summer meeting with technology policy experts to learn about the important part the engineer plays in government decisions. The students are also expected to develop contacts of their own in their chosen field of engineering policy research. The summer concludes with the writing of a research paper on their research.

## **Acknowledgments**

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# **U.S. Radio Spectrum Policy: A Political and Technological Perspective**

## **I. Introduction**

The United States policy on radio spectrum is poised for a change. Increased demand for spectrum is putting strain on the existing management system. Currently, spectrum is allocated for a specific service and then licenses are issued to systems for that piece of spectrum. This process gives government a great deal of regulatory power both in allocations and licenses. Strict regulations are required in order to limit levels of electromagnetic interference within each spectrum band. However, the government is running out of spectrum to allocate to new services and may be stymieing growth in the telecommunications sector. Multiple variants on solutions, both political and technical, relating to spectrum reallocations and spectrum sharing have been proposed.

The Radio Spectrum is a limited, but inexhaustible natural resource. Currently, it is defined as the frequencies from approximately 3kHz up to approximately 300MHz. Frequencies beyond or below this range have propagation characteristics that are not suitable for technological innovation for the purpose of telecommunications<sup>1</sup>. In particular, the frequencies of the radio spectrum below 2GHz are most attractive for such applications.

Radio communication affects almost every facet of society. The Department of Defense uses advanced communication systems to track terrorists and control military operations. Public safety departments use two-way radios and monitoring equipment to insure we are safe in emergencies and to help catch criminals. Scientists use the spectrum to study outer space and weather patterns. Its use is most obvious to the general public in the form of cellular and cordless phones, remote controls, wireless internet, global positioning systems, etc...

Telecommunications equipment requires interference free radio spectrum to operate efficiently. Interference that may result in distorted or jammed signals is often the result of congested frequency bands caused by too many users. Such interference could cause loss of a connection in the instance of a cellular phone or a real-time data connection, and should not be tolerated in areas of defense, public safety, and in certain private sector applications. Although spectrum must be allocated to suit these needs, it is generally agreed by all government entities, that while interference should not be tolerated, the radio spectrum must be publicly accessible for technological innovation and progress.

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<sup>1</sup> Webster's college dictionary defines telecommunications as "the science and technology of transmitting information, as words, sounds, or images over great distances, in the form of electromagnetic signals..."

Government entities, including the Federal Communications Commission (FCC), the National Telecommunications and Information Administration (NTIA), Congress, and the President, are put in charge of managing spectrum allocations for the United States. Such allocations must allow access to the spectrum by those who most need it. The government organizations and some industry are allocated over 50% of the most valuable radio spectrum<sup>2</sup>. Television broadcasters are allocated approximately 20% and unlicensed bands, in which anyone can operate without pre-approval, is approximately 7% of the most valuable spectrum. These are just a few examples<sup>3</sup>. Figure 1 shows which approximate frequencies are allocated to which general technologies throughout the Radio Spectrum.

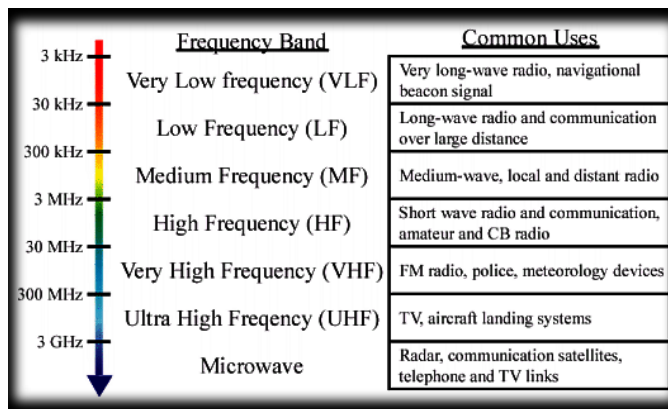


Figure 1: General Radio Spectrum allocations<sup>4</sup>.

Band sharing is practiced in many of the allocated bands. The allocation process determines which services can operate in a given range of frequencies. The FCC must then issue licenses to systems belonging to individual companies, organizations, etc., to operate in the band. All licenses are issued along with certain regulations. Most of the regulations are put in place to reduce the amount of interference in any one band. In order to share bands with minimal interference, systems must utilize various band sharing technologies. Not only do these technologies facilitate multiple user access of the same spectrum, they also help maximize the usage capacity of a limited resource.

The management and allocation of spectrum is inherently a political process. Radio spectrum users come to the government authorities in charge of policies and allocations and make requests. Through a conglomeration of technical advice and bureaucratic negotiations, user requests and allocations are considered according to their benefit to the American good. In the past, most spectrum needs have been satisfied without drastic change to spectrum management policies. However, should major reform be deemed necessary as a result of such requests, change in the established spectrum management system may take years to implement.

<sup>2</sup> Below 2GHz

<sup>3</sup> “The citizen’s guide to the airwaves,” poster, New America Foundation, 2003.

<sup>4</sup> <http://ihome.cuhk.edu.hk/~s016969/physproj/Spectrum/Radio/intro1.htm>

The sharing of spectrum bands, while governed by economic and legal systems, is made possible by technology. Spread spectrum techniques, software defined radios, and smart antennas better utilize the radio spectrum by allowing multiple systems access to the same frequency band without destructive interference. The engineering and development of such technologies has yet to be fully realized, but full integration is expected within the next decade. The further materialization of these, and other new spectrum sharing technologies, will both solve and give birth to a host of important radio spectrum policy questions.

The purpose of this paper is to briefly study the current United States Radio Spectrum policy. Included will be an overview of current governmental policies on radio spectrum, as well as proposals and recommendations from the public, private, and non-profit sector. Policies of concern will be those that specifically deal with spectrum allocations and band sharing. An overview of current and evolving spectrum sharing technologies will also be incorporated. Finally, the author's recommendations for the future of radio spectrum policy will be discussed.

## II. What is Spectrum?

The spectrum is made up of electromagnetic waves. These waves are usually defined by their *frequency*, measured in *hertz* (Hz), or cycles/second. The spectrum ranges from about 1Hz to  $10^{24}$  Hz, with visible light in the  $10^{15}$  Hz range. The wavelength<sup>5</sup> of visible light is about 30 micrometers as compared to the longest wavelength that makes up the Radio Spectrum at  $10^6$  meters.

The electromagnetic waves are created by alternating current in an antenna. These currents create magnetic fields in the air by continually changing the power in the antenna. The magnetic fields then induce a current in a receiving antenna. The fluctuating current that creates the fields is encoded with information based on its frequency, amplitude, duration, etc... The picture below is an example of how the amplitude of a carrier wave might be modulated to carry the information from an input signal.

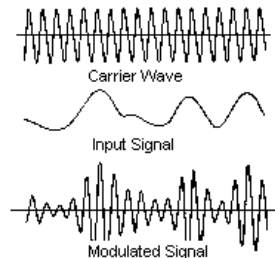


Figure 2: Amplitude modulation illustration<sup>6</sup>.

<sup>5</sup> Wavelength is the peak-to-peak or trough-to-trough distance between each wave.

<sup>6</sup> [www.scent01426.pwp.blueyonder.co.uk/.../Modulation/AM.htm](http://www.scent01426.pwp.blueyonder.co.uk/.../Modulation/AM.htm)

Such amplitude modulation is the how Amplitude Modulated radio, i.e. AM radio, is transmitted. The carrier wave in this example would be oscillating at the transmit frequency.

### III. Current Radio Spectrum Management Policies

The Federal Communications Commission serves as a regulator in all areas of wire line and wireless communication. In particular the Wireless Telecommunications Bureau (WTB) oversees the programs and policies involved in wireless telecommunications, excepting satellites and broadcast issues. The Media Bureau and the International Bureau regulate broadcast and satellite services, respectively. The WTB is in charge of most private radio services as well as public safety services. Since 1994, new spectrum licenses are determined by competitive bidding auctions that are administered through the FCC's website. A band is allocated for a particular service in a particular geographic location. Various companies that may be interested in such allocations are notified, and they register to bid. The auctions are held in a simultaneous multi-round approach consisting of thirty-minute time segments until the bidding stops. The winners of the auction receive an operating license of 5 years<sup>7</sup>. Auctions are an important process in the FCC's spectrum policies, however, only 7% of all Radio Spectrum is available for auction.

The National Telecommunications and Information Administration serves primarily to advise the Executive branch on telecommunications issues and govern the allocations of Federal spectrum use. The administration's advisory positions result from internal and external studies on commercial and technical issues. As the administrator of Federal spectrum, NTIA serves as a reactionary entity, catering to the demands of Federal departments in need of spectrum for national defense or safety<sup>8</sup>. As part of the Department of Commerce, they function as an important link between the telecommunications private sector and the government. Figure 3 shows the overlap of federal and nonfederal spectrum. Such overlap makes communication between the FCC and NTIA vital to efficient use of the spectrum.

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<sup>7</sup> [www.fcc.gov](http://www.fcc.gov)

<sup>8</sup> <http://www.ntia.doc.gov/ntiahome/aboutntia.htm>

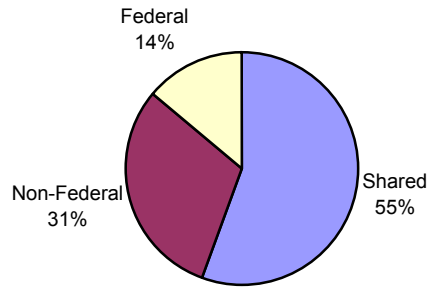


Figure 3: Federal and Non-Federal allocations of the Radio Spectrum<sup>9</sup>.

The International Telecommunications Union (ITU), a division of the United Nations, brings governments and private sector parties together to enhance telecommunications worldwide. The ITU-Radiocommunication (ITU-R) sector maintains a book of Radio Regulations that describe how the spectrum between 9kHz and 400GHz can be used and allocated worldwide. In the United States, ITU recommendations are generally adopted in order to ensure harmonization of equipment and to avoid interference in international air space. ITU-R hosts the Worldwide Radio Conference (WRC) every two to four years. Changes to the Radio Regulations are only allowed at these conferences.

#### IV. Need for Change in Radio Spectrum Policy

The last decade has seen significant growth in the telecommunications sector. New services and equipment have increased the revenue of the technology sector over 100% since 1990. Figure 3, from an ITU study, illustrates this growth. Increases in spectrum usage is apparent in the increased number of cell phones, wireless networking equipment, GPS receivers, etc... and new products and services that require spectrum are continuously emerging. In emergency public safety situations in which personnel rely on radios to communicate, it is crucial that there be enough spectrum available to ensure all radios used are interoperable and safe from interference. It is imperative that regulatory authorities promote a management system that allows for maximum innovation and economic growth in this sector by allowing access to those who would most make possible this end while still insuring the public's safety.

<sup>9</sup>“Comprehensive Review of U.S. Spectrum Management with Broad Stakeholder Involvement Is Needed,” General Accounting Office, January 2003, GAO-03-277, <http://www.telecomweb.com/papers/spectrum.pdf>.

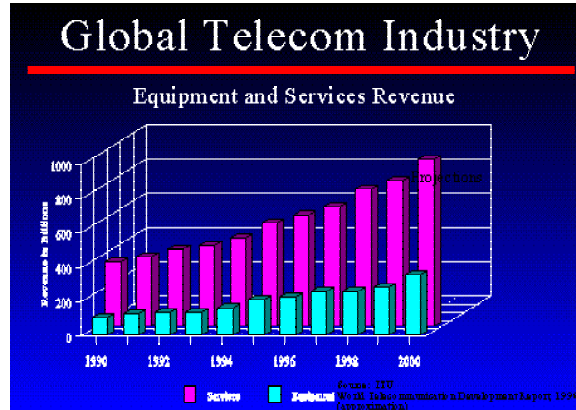


Figure 3: Global telecom industry equipment and services revenue<sup>10</sup>.

In addition to the need for more spectrum, new services that require access, but not full use, of spectrum bands are providing never experienced before questions of policy, for example, the new Ultra-Wideband (UWB) service. Since UWB can operate over the entire frequency range policy makers must decide power levels for each service UWB may interrupt in each band. UWB will be discussed in depth later in this document.

## V. Policy Problems and Proposed Solutions

The policy questions that abound concerning spectrum are equally matched by proposed solutions. The General Accounting Office issued a study on spectrum management in January 2003 with the final suggestions to Congress and the President that a team from different agencies of the federal government be formed to study the best way to reform spectrum policy<sup>11</sup>. On June 5<sup>th</sup>, 2003 President George W. Bush issued a Memorandum regarding spectrum which called for the formation of an interagency committee, or the “Task Force,” consisting of the Departments of State, Homeland Security, Defense, and Commerce to name a few, as well as the National Aeronautics and Space Administration and the Executive Office of Science and Technology Policy. The Task Force is commissioned to look at ways to

- (a) foster economic growth; (b) ensure our national and homeland security; (c) maintain U.S. global leadership in communications technology development and services; and (d) satisfy other vital U.S. needs in areas such as public safety, scientific research, Federal transportation infrastructure, and law enforcement,<sup>12</sup>

through the betterment of radio spectrum policy. The Task Force is scheduled to have reports by June 5<sup>th</sup>, 2004. It is expected that these reports will be more comprehensive than past studies done by the FCC, NTIA, or other agencies, but

<sup>10</sup> “World Telecommunications Development Report,” International Telecommunications Union, 1996.

<sup>11</sup> See footnote #9

<sup>12</sup> Bush, George W. “Presidential Memo on Spectrum Policy,” June 6<sup>th</sup>, 2003.

will undoubtedly draw some of the same conclusions. The next two sections of this paper will examine the main problems and the proposed solutions to the primary issues that are concerned in meeting the President's goals. These issues are categorized by their solutions to policy problems as they are related to the reallocation of existing spectrum and spectrum sharing.

### **a) Reallocation of Existing Spectrum**

The television broadcast debate has been one of the most heated spectrum challenges in recent months. Analog television broadcast channels take up approximately 20% of the most valuable spectrum. Seven years ago in the Telecommunications Act of 1996, Congress allowed the FCC to give additional bands of spectrum to television broadcasters so they could make the transition to digital broadcasts. Digital broadcasts are better quality, easier to detect, and make use of higher, less valuable frequency band. Broadcasters were required to move from analog to digital broadcasts by 2006, but only if 85% of televisions are capable of digital reception by that date.

Seven years later, broadcasters are still in no hurry to make the expensive transition and are holding large quantities of unused, valuable spectrum. As of 2002, only channels 52 through 69<sup>13</sup> have switched, and not many more are expected to switch in the near future<sup>14</sup>. Most Americans subscribe to cable and 85% are not going to buy a digital antenna when the broadcast channels are available through their cable operator. The Cato Institute<sup>15</sup> advocates the abandonment of the Digital Television experiment. Currently television broadcasters are allocated about 6MHz each of valuable frequency for analog broadcasts and another 6MHz each for their switch to digital. This spectrum was given to them free of charge because they were providing a public service. Cato says the government should take back the spectrum allocated for digital broadcasts and allow it to be put into the auctioning pool for better use<sup>16</sup>. The New America Foundation, another non-profit policy advocacy group, makes the point that within the TV broadcast frequencies there is much unused spectrum. Taking the space and time factors into consideration, unlicensed users should be able to use the open spectrum while broadcasters make the transition to digital, at which point all six megahertz for each switched channel should become unlicensed<sup>17</sup>.

The success of unlicensed devices has raised awareness of the need for more unlicensed spectrum. Approximately 15 million wireless fidelity, often referred

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<sup>13</sup> 698 MHz through 806 MHz

<sup>14</sup> Kwerel, Evan, "A Proposal for Rapid Transition to Market Allocation of Spectrum," FCC Working Paper Series, November 2000, p. 30.

<sup>15</sup> The Cato Institute is a non-profit public policy research foundation.

<sup>16</sup> Cato Institute, "Cato Handbook for the 108<sup>th</sup> Congress," p.426-428.

<sup>17</sup> Snider, J.H. and Max Vilimpoc, "Unlicensed Sharing of Broadcast Spectrum," New America Foundation, Spectrum Series Issue Brief #9.

to as WiFi, adapters and 4.4 million access points were sold in 2002.<sup>18</sup> That means approximately 2.5% of all computers in the world became capable of using WiFi to connect to the Internet within the last year. WiFi is cheap and easy to install and operate for the average consumer, but is also popular in wide-area networks to provide an alternative to wired connectivity. The potential of wireless local area networks in applications beyond wireless internet access make it essential that such technological innovation, such as WiFi and UWB, be encouraged.

Gradual steps are being taken to open up more spectrum for unlicensed devices. In January of 2003, the Jumpstart Broadband Act<sup>19</sup> was introduced in the Senate. The Act permitted access to 255MHz of government spectrum in the 5GHz band for broadband networking devices. The Federal entities involved negotiated interference standards with the wireless broadband equipment providers and the spectrum was allocated for shared use by the end of January<sup>20</sup>. As shown, efforts by Congress or the President to influence spectrum regulatory authorities are an efficient means of expediting policy.

Market-based allocation is another policy topic that has been presented for consideration, and has been lauded as the true capitalism-based approach. The current auctioning process still places many restrictions on licensees. In a market-based approach the FCC would not determine which bands must be used for which services, instead, the market would determine allocations. The commercial and public sector would be in charge of coordinating their interests with the allocations of the ITU, determining interference, and finding their own least cost scenarios. The FCC would be in charge of issuing licenses and monitoring interference. In addition, licenses would be issued for three dimensions: space, time, and frequency<sup>21</sup>. Prospective problems include monopolies forming to bar competitors and unstable markets that would hinder long term investments in certain frequency specific technologies. While full market-based allocations may be feasible in the future, current transition to such a system is not likely.

Secondary Markets have been implemented to some extent by the FCC and are more stable and less revolutionary than a fully market-based allocation system. In a secondary market system, spectrum license owners are able to sell parts of their spectrum to other systems for periods of time. The FCC adopted a Notice of Proposed Rulemaking<sup>22</sup> regarding secondary markets in November of 2000 in order to better define the rights of spectrum licensees in regards to secondary

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<sup>18</sup> "Bubble Trouble," *The Economist*, June 26<sup>th</sup> 2003.

<sup>19</sup> S.159, 108<sup>th</sup> Congress, introduced by Senators Boxer and Allen.

<sup>20</sup> "Agreement Reached Regarding U.S. Position on 5GHz Wireless Access Devices," U.S. Department of Commerce News, January 31<sup>st</sup>, 2003.

<sup>21</sup> Kwerel, Evan, "A Proposal for Rapid Transition to Market Allocation of Spectrum," FCC Working Paper Series, November 2000. The proposal also includes details of how this market allocation approach would be implemented from the current system.

<sup>22</sup> "Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets"; Notice of Proposed Rulemaking (FCC 00-402).

markets. No formal decisions have been made, but most governmental and private organizations are in favor of better-defined, but still loose regulations for secondary markets.

From an international standpoint on all policy issues, it is important that the United State's Radio Spectrum policies are complimentary to the ITU's allocations in order to move towards greater harmonization of global communications and ubiquitous access. Allocations are particularly important in areas in which American services may infringe on another country's airspace. Such would be the case in airline and satellite communications, and near geographical borders. In terms of economic reasons to harmonize spectrum, mass production of telecommunication equipment for international import and export by the private sector is more efficient. Also, it is important to note that the Department of Defense must negotiate use of radio airspace in every country or region it operates in. While the DoD is searching for a technological solution to resolve this issue, spectrum licenses in foreign areas are easier to obtain if the spectrum is already allocated for defense system services.

In order to implement any new system or policy, spectrum may have to be taken away from some services. In doing so problems arise regarding the costs of relocating as well as the compatibility with surrounding systems. In an effort to deal with relocation costs of government spectrum "The Commercial Spectrum Enhancement Act" was introduced to the Senate by Senator John McCain in April of this year. The Act establishes a fund to ensure compensation to Federal entities that lose spectrum reallocated for commercial use and is making its way through Congress with a great deal of potential<sup>23</sup>. In the private sector, compensation from outside sources is necessary, as seen in the markets models, and makes sense. However, in Senator McCain's bill, the money the federal government spectrum users are allocated may appear as profit in the next year's budget. The compensation for relocation of systems will need to be assessed and guaranteed in the budget for each year.

## **b) Spectrum Sharing**

Electromagnetic interference is the primary issue of concern in any spectrum-sharing situation. Politically speaking it is the driving force behind the need for regulations. Regulations control the power output levels and geographical area in which transmission is allowed in order to keep interference at a minimum. Currently, title 47 of the FCC's Code of Federal Regulations contains the rules pertaining to interference spread out over 3,600 pages. The regulations are developed through intensive simulations of real-time environments.

Regulations in the case of technologies such as UWB are difficult to develop. The problem in this instance arises from the large expanse of spectrum covered and the UWB device's interaction with so many other systems. The Worldwide

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<sup>23</sup> McCain, John, "The Commercial Enhancement Act," Senate bill 865, 108<sup>th</sup> Congress.

Radio Conference (WRC) in June and July of 2003 discussed this issue and commissioned a study to investigate such technologies. The main concern with UWB is that it will raise the level of the noise floor and eventually cause harmful interference.

In the FCC's "Spectrum Policy Task Force Report," released in November 2002, the idea of an "interference temperature" is proposed<sup>24</sup>. The measurement system, though still ill defined, would theoretically take into account the amount of interference, generally from unlicensed underlying devices, allowed in a band. Developing a comprehensive and simplified measurement of interference is important for spectrum users to understand the limitations imposed on them in a spectrum sharing environment.

Digital commons are another proposal of the "Spectrum Policy Task Force Report." The Report advocates a partial conversion to a commons approach in higher bands that are used less frequently. The commons approach means that these bands will be opened up for use by whomever regardless of the service they supply. The Report cites the success of unlicensed devices in lower bands as reason for opening up more digital commons<sup>25</sup>. Other advocates of commons have suggested opening up doing away with current licensing and opening up a large portion of spectrum for market- allocations, and another large portion for digital commons. The success of each experiment in promoting technological innovation and economic stimulation could be assessed after a certain period in time<sup>26</sup>. The commons approach's success will be dependant on the further development of technology.

Some spectrum is allocated to have primary services with priority rights and secondary services that must not cause interference to the primary service. Examples of sharing are in secondary markets, by federal and non-federal users as seen in figure 3<sup>27</sup>. The recent decision to allow broadband networking devices, such as WiFi, into a section of federal 5GHz spectrum is an example of such sharing. In order to limit interference in these instances, the FCC places regulations on power and geography. These regulations are based on live and virtual simulations of interoperating equipment. However, different types of transmission techniques, changes in geography, and noise levels make simulations complex and often impossible to keep accurate. New modeling and simulation technologies are constantly in development, but new signaling and adaptive transmission techniques are also constantly raising the level of complexity. The implementation of these techniques may rely more on experimentation and less on simulation to evaluate the harm they may present.

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<sup>24</sup> "Spectrum Policy Task Force Report," Federal Communications Commission, ET Docket No. 02-135, p. 27-30.

<sup>25</sup> See footnote #24, p. 40.

<sup>26</sup> Benkler, Yochai, "Some Economics of Wireless Communications," *Harvard Journal of Law & Technology* Volume 16, Number 1 Fall 2002, p. 81-82.

<http://jolt.law.harvard.edu/articles/pdf/v16/16HarvJLTech025.pdf>

<sup>27</sup> GAO-03-377, p.8.

Multi-carrier modulation (MCM) is a signaling scheme by which data in the form of bit streams are spread over a large bandwidth and is an example of these complex sampling techniques. Since less of a signal occupies any one band at any one time, the noise from the signal is spread out over a range of frequencies. Often MCM signals look like background noise. The military first developed MCM in the 1950's to hide their transmissions and prevent jamming. Current variations on MCM include Orthogonal Frequency Division Multiplexing (OFDM), Time Division Multiplexing, and Frequency Division Multiplexing. OFDM is used in wireless local area networks and will probably be the signaling method of choice for DTV<sup>28</sup>. MCM reduces the noise in any one frequency, but it also may raise the noise floor over a broad range of frequencies. Increases in the noise floor by even a few decibels may affect coverage, system capacity, and reliability of data throughput in many instances<sup>29</sup>. Figure 2 illustrates how signals spread out and remain below the noise level, i.e. the level at which interference may occur.

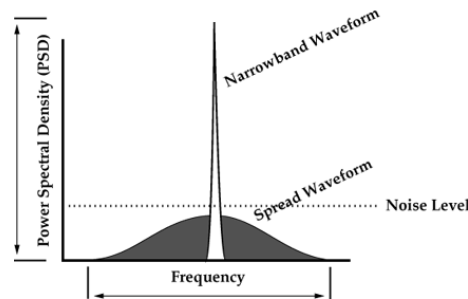


Figure 4: Multi-carrier modulation illustration<sup>30</sup>.

UWB is a somewhat similar technology to MCM in that it spreads out a data signal over a large range of frequencies. However, rather than splitting data into bit streams like MCM, UWB uses short simultaneous pulses that can be as small as a pico-second each. The receiver must look for a familiar sequence in these pulses in order to decipher the data<sup>31</sup>. The technology was developed by the military in the 1950's, but was not released for public use until 1994. The technology has rapidly expanded since then and has been a topic of discussion by the Institute of Electrical and Electronic Engineer's (IEEE) standards group for Wireless Personal Area Networks<sup>32</sup>. In April 2003, Intel demonstrated a form of UWB suitable for local area networks operating at 220Mbps. Current Wireless Fidelity operates at 11Mbps and consumes significantly more power. In February of 2002, the FCC decided to allow UWB into most bands with highly restrictive

<sup>28</sup> [www.searchnetworking.com](http://www.searchnetworking.com)

<sup>29</sup> Kwerel, p.10

<sup>30</sup> source: <http://murray.newcastle.edu.au/users/staff/eemf/ELEC351/SProjects/Morris/project.htm>

<sup>31</sup> [www.webopedia.com](http://www.webopedia.com)

<sup>32</sup> The Institute of Electronic and Electrical Engineers-Standards Association, 802.15 Working Group.

power level regulations<sup>33</sup>. As of right now, UWB's technological potential seems to rival WiFi, Bluetooth, and current cellular phone network transmission methods<sup>34</sup>.

Adaptive antenna arrays are a type of smart antennas that take advantage of the space, as opposed to the frequency, domain to use spectrum fully. The antennas track both the signal and the interference sources. The information signal source is filtered from the interference and amplified. The information and interference signals source's location are used in a series of digital signal processing and complex algorithms to determine the strength and direction for the return signal. Adaptive antenna arrays allow transmitters to have strong signal strength to receivers while staying within certain power limit regulations<sup>35</sup>. In layman speak, it is like a cocktail party in which a listener, i.e., the base station, can be involved in a conversation with two people, but by zoning them out and cocking an ear in the right direction, can listen to a quieter conversation going on a few feet away. Adaptive arrays are of most use in cellular-phone networks and already provide service to 15 million people worldwide. Base stations that use this technology are more expensive than normal, but make-up costs since less stations are needed to cover the same geographical area<sup>36</sup>. Figure 5 illustrates how lobes of adaptive antenna arrays can follow two cellular phones using the same frequency.



Figure 5: Adaptive antenna array illustration<sup>37</sup>.

One of the recent technology buzzes has been the further development of the Software Defined Radio (SDR), which is closely related to smart antennas. SDR's have been defined as, simply, a radio with "enough programmability."<sup>38</sup> Cognitive radios are software programmable, but also take the definition of SDR's one step further. They are able to learn about the RF environment, react according to usage patterns, and quickly change bands or power levels, should a primary user of the spectrum band become visible. Figure 5 illustrates the

<sup>33</sup>“Revision of Part 15 of the Commission’s Rules Regarding Ultra-Wideband Systems,” FCC, February 14<sup>th</sup>, 2002. [http://hraunfoss.fcc.gov/edocs\\_public/attachmatch/FCC-02-48A1.doc](http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.doc)

<sup>34</sup> Briody, Dan. “Who’s Afraid of Ultra Wideband?” [www.redherring.com](http://www.redherring.com), June 18, 2002.

<sup>35</sup> [http://www.iec.org/online/tutorials/smart\\_ant/glossary.html](http://www.iec.org/online/tutorials/smart_ant/glossary.html)

<sup>36</sup> Cooper, Martin. “Antennas get Smart,” *Scientific America*, July 2003, p.55.

<sup>37</sup> See footnote #28.

<sup>38</sup> Berezdivin, Robert, et.al. “Next Generation Wireless Communications Concepts and Technologies,” *IEEE Communications Magazine*, March 2002, p. 114.

average power and penetration distances of three very different signaling technologies.

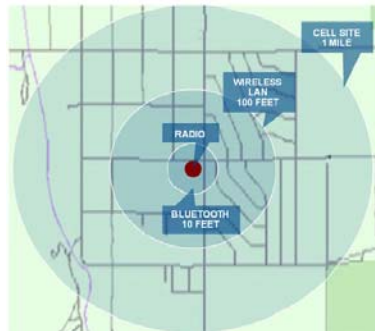


Figure 6: Cognitive radio adaptability illustration<sup>39</sup>.

Through the use of a cognitive radio in a piece of telecommunications equipment, the device could theoretically switch functions according to the users need. In other words, a single device could download your address book from your computer using bluetooth, access your wireless local area network with WiFi, and be used as a personal communication system<sup>40</sup>. There are functioning cognitive radios in existence. However, they are still in the early stages and the FCC has yet to define regulations for them. Like UWB they present distinct, new policy issues: cognitive radios can fall under the classification of multiple types of services and multiple frequency bands. IEEE, among other organizations have supported the view of relaxed regulations and support for SDR and other frequency conserving technologies.

In an effort to establish a framework of protocols to streamline adaptive wireless systems like SDRs, the Defense Advanced Research Project Agency (DARPA) has begun to develop the neXt Generation, or XG, project. The project promises to allow for systems that would negotiate their policies, regulations, and priority agreements with each other while maximally exploiting time, frequency, geography, and coding techniques. XG is especially important to DARPA because of the potential it has for use in other countries: the United States military could theoretically use these XG enabled devices without having to negotiate spectrum usage licenses with foreign regulatory authorities. However, as illustrated by DARPA's initial military interest in the creation of the internet, the commercial possibilities of XG will become more apparent once the military use becomes a reality. Currently, the XG program is in Phase II of the project which consists of thorough prototypes and computer models. Next year phase III should be implemented in which the military will have working XG models. As seen in figure 7, SDR's are expected to be an integral part of XG when it is available for commercial implementation in 2008.

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<sup>39</sup> Fette, Bruce, "SDR Implementation for the Cognitive Radio," presentation by General Dynamics, May 15<sup>th</sup>, 2003. [http://www.gd-decisionssystem.com/radiosystems/pdf/FCC\\_Cognitive\\_Radio\\_Fette\\_v7.pdf](http://www.gd-decisionssystem.com/radiosystems/pdf/FCC_Cognitive_Radio_Fette_v7.pdf).

<sup>40</sup> See footnote #32.

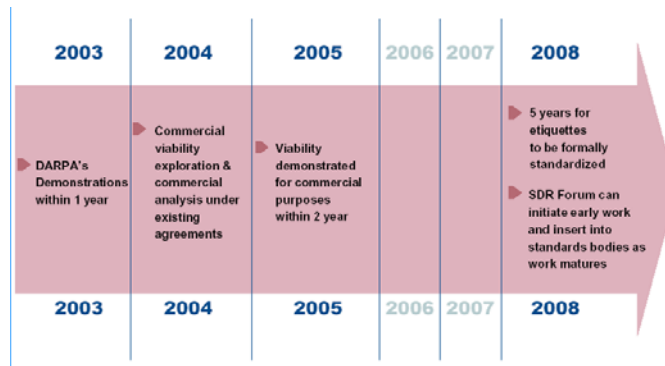


Figure 7: Timeline from XG initial demonstrations to SDR implementaion<sup>41</sup>.

## VI. Conclusions

The processes used by government authorities to accept new technology and policy are slow and based on a command and control architecture. While the government has been working towards a less regulated and more market friendly approach to spectrum management, outside authority's influence on the FCC and NTIA by Congress and the President is necessary in order to keep the big picture in focus and ensure a universal solution. Technology will only cede its benefits to the public if the government keeps the playing field open for new innovation. In order to do so the federal government should allow more usage of unlicensed devices as secondary services in federal spectrum, allow secondary markets in non-federal spectrum, and work to increase the availability of market-based licensing through reallocations.

Before drastic changes to Radio Spectrum Policy are made, a healthy perspective of the market, the available spectrum, and the viable technologies is imperative. While the market can be difficult to judge before hand, and the available spectrum depends a great deal on regulations imposed by the government, the abilities of technology should be evident through experiment and simulation. In the cases of adaptive antenna arrays, UWB, SDRs, and XG there is the potential to revolutionize the way in which spectrum will be viewed, but only if policy is flexible enough to allow such change. "Any precedent-setting, disruptive technology faces resistance, but you have to see through the fury of the moment and filter for the truth," says Michael Gallagher, deputy assistant secretary at NTIA<sup>42</sup>. The success of these technologies in the general market will depend a great deal on what "truth" is reached by the policymakers involved.

The primary objective of spectrum policy reform should be to allow the maximum access for commercial use while not in any way compromising the public's safety or national defense. The issue of spectrum reform has been evident for many

<sup>41</sup> See footnote #32

<sup>42</sup> Briody, Dan, "Who's afraid of ultra wideband?" [www.redherring.com](http://www.redherring.com), June 18<sup>th</sup>, 2002.

years and it is unlikely that it will go away without a major shift in the political structure of its management. A planned gradual transition to a more market-based management and spectrum sharing system will allow maximal access. The nature of the problems and solutions are so diverse, and in many cases ambiguous, that a transition to a one-size fits all market-based or technologically based solution from the current status is highly impractical. However, as the FCC and NTIA work to open up more spectrum for auction and underlay<sup>43</sup>, and as engineers continue to exploit narrow-bands of spectrum to their maximum capacity, it should be expected that the markets and the technology will find a way to best suit the public's needs.

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<sup>43</sup> Underlay describes the practice of allowing a secondary service to operate in a primary services band as long as the secondary service stays below a certain power or interference level.