Reeling In Cognitive Radio: The Issues of Regulations and Policies Affecting Spectrum Management

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Abstract

One of today's most important developing wireless technologies is Cognitive Radio (CR). In our current fixed-assignment spectrum management policy, much of the available frequencies go unused. CR aims to make use of this unutilized space to provide wireless broadband services. This paper aims to give a background to CR and describe the key players in standardization and allocation of the unused spectrum. Furthermore, it discusses the policies and policy makers that are guiding the future of CR.

Keywords: Cognitive Radio, Regulations, Policies, standardization and Spectrum Management.

1. Introduction

1.1 Origins of Cognitive Radio

Cognitive Radio (CR) has its origins in the Defense Advance Research Products Agency (DARPA). An employee of DARPA, Dr. Joseph Mitola, co-authored the paper *Cognitive Radio: Making Software Radios More Personal* with Gerald Q. Maguire, Jr., which played a huge role in the concept of CR. CR is built on Software Defined Radio (SDR) technology, and is on the cutting edge in the software defined radio community. This type of technology is on the forefront and used primarily in military applications. The U.S. Navy is the largest consumer of Software Defined Radio (SDR). The Navy replaced a whole room of radios with a single rack of Digital Modular Radio (DMR). The DMR (Figure 1) is four radios in one and currently operating on submarines and surface ships [9].

Figure 1. Digital Modular Radio (DMR) [10]

For the U.S. Navy, the software-based Digital Modular Radio (DMR) is replacing room of radios with a single rack of DMR's as shown in Figure 1. The unit is four-channel full duplex system that is essentially four radios in one. Currently operating on submarines and surface ships around the world, the DMR (AN/USC-61) illustrates the viability of Software Defined Radios on active duty.

Although these types of radios are only being used by the military the need for smart radios in everyday transmissions is dire and can mean the difference between life and death in some cases. The need for Cognitive Radio arises from the increasing amount of interference on different frequencies. All of this interference has caused a transmission bottleneck. To solve this problem CR has the ability to detect when other transmitters interfere with your reception. When the interference is detected, it can respond by switching you to another frequency with less traffic. The changeover would be transparent to the user and allow the transmission to continue as if nothing had happened [1].

1.2 Description of Cognitive Radio

On the basic level, CR is an advanced form wireless communication that uses radio waves on various frequencies to send information from one point to another. It is considered to be an extension of SDR implementing spectrum sharing to avoid licensed and unlicensed users from clashing. It has several main functions: spectrum sensing, spectrum management, spectrum mobility, and spectrum sharing [2]. Spectrum sensing describes how CR detects unused segments of the spectrum and assigns them without interfering with any other users. Because some users have different spectrum requirements, CR employs spectrum management techniques to meet various service quality requirements. In addition to finding unused frequencies, cognitive radio can dynamically switch users to find the optimum frequency during run time by utilizing its spectrum mobility and sharing techniques [2].

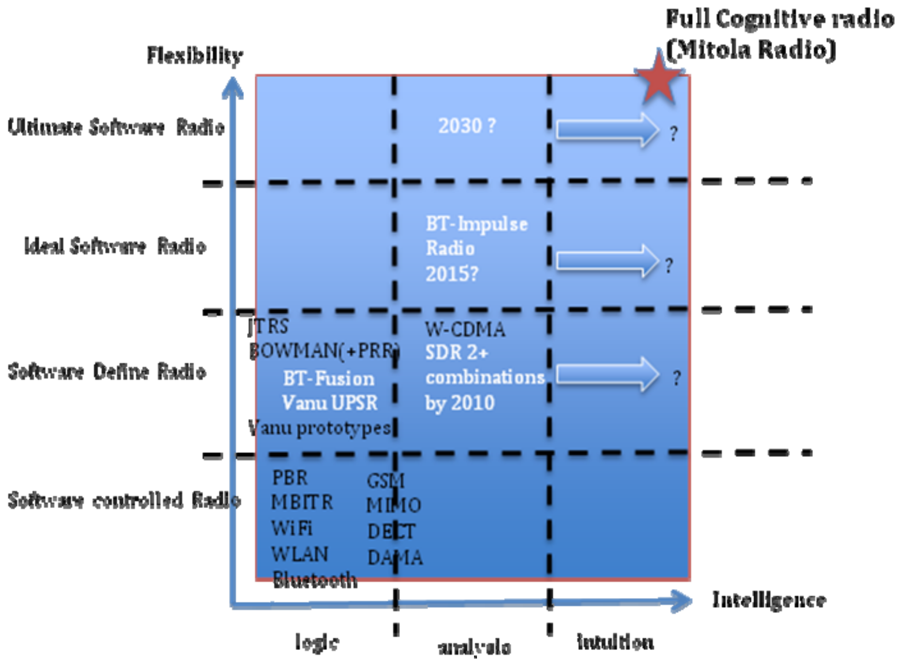

Figure 2. Matrix of Flexibility of Hardware and Intelligence to Control (or Configure) the Hardware [15]

The matrix shown in Figure 2 describes the potential of full CR with respect to Flexibility (shown on the Y-axis) and Intelligent Signal Processing (shown on the X-axis). It is obvious to see full CR's potential vastly outmatches its competitive mediums like WiFi, WLAN, and Bluetooth.

The progression of CR is heavily influenced by two driving forces: market demands and physical constraints. Market forces demand CR be a reliable medium to send data, because developers of competing mediums (wired, microwaves, WiFi) are striving to do the same. As with any wireless medium, reliability is a prominent concern. The physical constraint comes from the nature of the electromagnetic spectrum. The spectrum is finite in size, and although it can be divided into a larger number of frequencies, it is still a finite (and therefore scarce) resource. As with any finite resource, a sought after method is one that utilizes the resource efficiently. The developers of CR have done this by procuring a radio that is able to detect its surroundings and find unused signals. This significantly decreases unused/wasted frequencies, maximizes the usage of the electromagnetic radio spectrum, and improves cognitive radio's overall marketability.

Since its inception in 1999 CR has grown around two primary goals: reliability and efficiency. Cognitive radio developers are striving to make CR reliable and efficient [10]. To be marketable to the public and grow as a significant telecommunications medium, CR must meet these two goals.

2. Spectrum Management and Protecting License Holders

In order to become successful, there are several main operational issues CR must overcome, the first being the issue of spectrum management. The main advantage of CR over traditional wireless network technology is its ability to make dynamic use of unused spectrum space. This means that CR can make use of parts of the spectrum reserved for other purposes, such as TV broadcasts. Because the spectrum is divided up in a fixed-spectrum assignment policy, even if the space is unused, it is still assigned to the license holder by the Federal Communications Commission (FCC), or the National Telecommunications and Information Administration (NTIA). If a CR wishes to make use of an unused portion of the spectrum, the original spectrum holder's rights must be protected. As the primary user, the license holder must be protected from interference that could be caused by CR's use of a hole in the spectrum. This presents a unique problem, as CR and the organizations that regulate the spectrum must find a way to allow CR to reach its full potential, while still respecting the rights of the primary users of spectrum space. There are some techniques available that allow CR to safely make use of spectrum space without interfering with the services offered by licensed holders. These key factors effectively implement CR a viable technology, and are working to convince the regulatory bodies that CR should be allowed to make use of this spectrum space.

Currently, the FCC (Federal Communication Commission) has spectrum space set aside for unlicensed use. CR is ideal for making use of this space in the 5 GHz band. At the Federal Communication Commission's 2003 World Radio communication Conference (WRC-03), the regulatory community agreed on a method for 5 GHz spectrum sharing of radar and wireless access systems [8]. The basis for the sharing was an agreement on the use of Dynamic Frequency Selection in 5230- 5350 MHz and 5470-5725 MHz range [8]. The FCC regulations concerning this unlicensed space follow.

"(ii) Channel Availability Check Time. A U-NII (Unlicensed National Information Infrastructure) shall check if there is a radar system already operating on the channel before it can initiate a transmission on a channel and when it has to move to a new channel. The U-NII device may start using the channel if no radar signal with a power level greater than the interference threshold values listed in paragraph (h)(2) of this part is detected within 60 seconds.

(iii) Channel Move Time. After a radar's presence is detected, all transmissions shall cease on the operating channel within 10 seconds. Transmissions during this period shall consist of normal traffic for a maximum of 200 ms after detection of the radar signal. In addition intermittent management and control signals can be sent during the remaining time to facilitate vacating the operating channel.

(iv) Non- occupancy period. A channel that has been flagged as containing a radar system, either by a channel availability check or in service monitoring, is subject to a non-occupancy period of at least 30 minutes. The nonoccupancy period starts at the time when the radar system is detected [8]."

These licensing regulations express how future regulations could be passed that respects both the rights of the license holders and CR. Currently, unlicensed space is available on a first-come, first-serve basis, and as time goes by, unlicensed space becomes increasingly congested. In the unlicensed spectrum there are no safeguards to prevent a user from occupying a large amount of available space indefinitely. This could cause future problems with other users competing for that unlicensed space. For CR to reach its full potential, it must also be able to access unused licensed spectrum space.

One of the first steps CR must take to find unused spectrum space is to obtain an estimate of the Power Spectral Density (PSD) of the radio spectrum. This requires extremely sensitive radios that can measure signals at their cell edge [13]. If the radio is sensitive enough it will detect unused space. CR monitors the constantly changing spectrum, and if necessary, switches bands. If the radio detects unused space that is actually in use, the signal used by CR will interfere with the signal already being used, causing interference with the primary user. This is referred to as "the hidden node problem" [7].

Another aspect of this problem occurs when the primary user tries to access part of the spectrum currently in use by a CR. If the primary user attempts this, their signal and the CR signal will create interference. The CR must be able to detect this situation, and respond accordingly. In addition to being able to detect whether spectrum space is being used or not, CR will need to be able to detect the transmission power level. Doing so will allow the device to operate without raising the noise floor of the primary user's device beyond a specified amount [13]. The CR must be able to make use of the bandwidth without generating a signal that could raise the noise floor. This requires the CR to know two things: an estimate of the signal bandwidth used by the primary user, and the distance between the CR and the victim device [12]. This is tricky because each bands has a different values that must be calculated. Also the propagation path from the CR transmitter to the primary user's receiver could be very complex. The signal bandwidth can be used to determine the amount of noise the primary user's device can tolerate without interference, and the distance between the CR and signal device can be used to determine the signal strength of the primary user's device [7]. CR will never succeed unless both of these issues are adequately addressed. If primary users of spectrum space face any danger of interference with their services, it is very likely that they will deny any use of their spectrum space.

The FCC controls commercial and state and local government wireless users, while the NTIA regulates federal government users. These regulations cover operating frequency, effective radiated power limits, antenna height, emission type, and bandwidth limitation [12]. CR is subject to regulations from both these organizations, which can have different regional scopes and operating conditions. Since CR seeks to make use of different bands of the spectrum, it must be aware of regulations that differ per frequency band, service type, and spectrum management model [12]. If CR is not fully aware of these regulations, it runs the risk of causing interference to the primary user of that spectrum space. In order to make this possible, regulations should be made available so CR can access them in a machine-readable format [7]. This information would need to contain both allocations and spectrum sharing technical parameters [13]. Also included would be frequencies which are never to be accessed, even if unused. Such frequencies would include distress and safety channels, Radionavigation, and also Fixed Satellite bands [12].

From an economic standpoint, for CR to be effective it must make use of spectrum used by the television and phone industries. These companies will be pioneering CR and encouraging its development. In many cases, the services offered by these companies over CR could be in direct competition with the services offered by the companies that are the original license holders of the spectrum. For example, CR could open up the possibility of high speed wireless broadband video, and directly affect the earnings of television companies. Because of this, the owners of the spectrum might be unwilling, or even opposed to the sharing of their spectrum, even if it means possibly crippling CR.

3. Policy and Policy Makers

Due to the large demand for intelligent radios and the increasing numbers of wireless services crowding frequencies, CR has become a necessity, but so has spectrum management. This has caused various organizations to take notice and provide some standardization to spectrum allocation. As we have discussed, CR can sense its surroundings and learn from past experiences to utilize the unused spectrum. This unused spectrum has to be allocated properly without interfering with the transmission of other users. Therefore it must intelligently detect whether or not a segment of the spectrum is currently being used.

In order for licensees, regulators, and the general public to have comprehensive use of the spectrum, certain policies and procedures have to be in place. Organizations such as the Federal Communications Commission (FCC), Institute of Electrical and Electronic Engineers (IEEE), SDR Forum, and industry partners such as General Dynamics, Rockwell Collins, Vanu are involved in the standardization, protocols, and proper allocation of the spectrum [9].

The FCC is an independent government agency reporting to the Congress. They are responsible for the regulation of interstate and international communication by radio, satellite, television, wire, and cable. It is comprised of many different bureaus, but the bureau of wireless telecommunications is the control point for radio spectrum management. Therefore, the FCC has regulatory considerations for a functional solution to this growing problem. It has conducted Cognitive Radio Workshops, a taskforce charged with the tasks of gathering, analyzing and reviewing spectrum allocation [9] as shown in Figure 3.

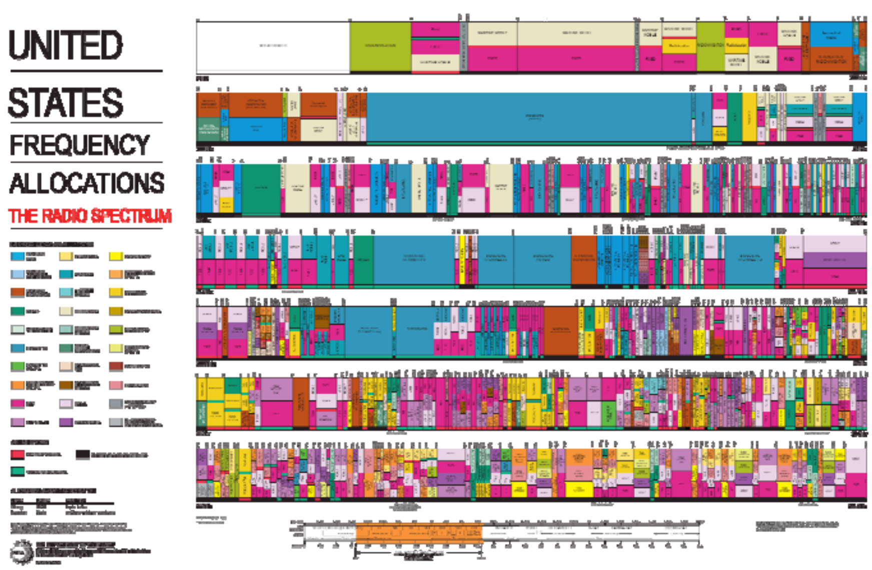

Figure 3 US Frequency Allocations

Regulatory considerations at the CSS level are a key part of the software radio story. The FCC even offers a number of CR workshops where industry and FCC regulators work to gather, analyze, and review spectrum allocations, use and licensing issues for the future. (Image courtesy of the U.S. Department of Commerce, National Telecommunications and Information Administration, Office of Spectrum Management, October 2003.) [14]

The FCC works to approve certain devices like SDRs that protect the confidentiality of software that controls the security measures regarding software defined radios. They continue to push for greater spectrum sharing in any band where licensed users agree to share the radio spectrum. The FCC also has industry partners that it is working with to resolve spectrum issues. In 2005, Vanu, Inc., a partner of the FCC, used the first Global System for Mobile Communications (GSM) base station with an RF converter. This converter makes the radio signal processable using a high-performance laptop [1]. The FCC has researched the spectrum and found that 70 percent of the allocated spectrum may be sitting idle at certain times of the day, even though it may be spoken for.

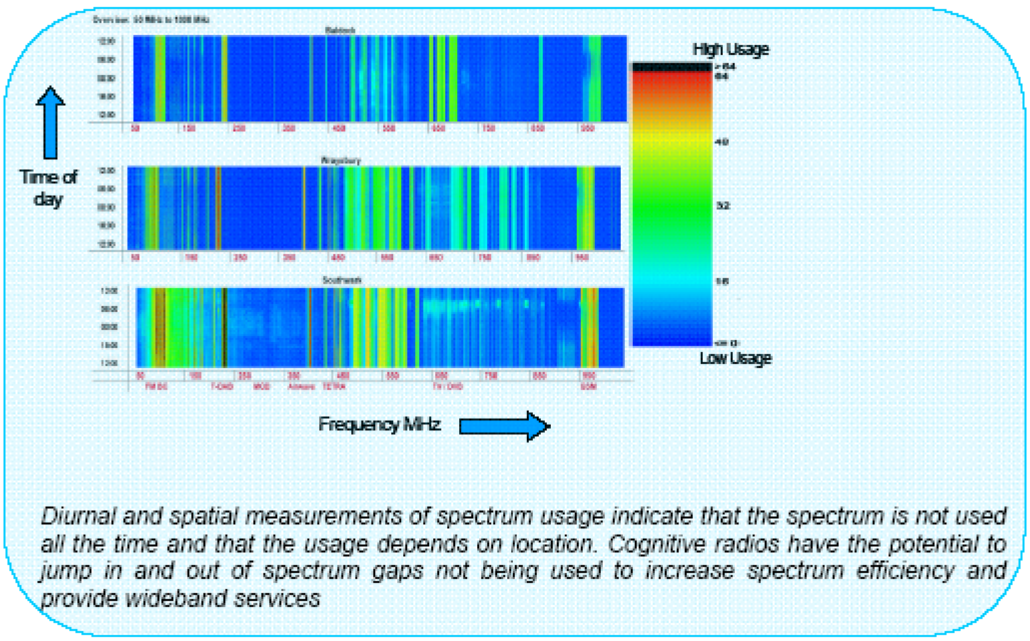

Figure 4 Not All the Spectrum is Used in Space (Geographic Location) or Time [14]

One solution for efficiently sharing the spectrum comes from a professor at the University of California. He suggested that the FCC gets priority, as the owner of the spectrum, while other devices divide the unused spectrum among themselves [16].

The Institute for Electrical Engineering (IEEE) is a leader in developing industry standards and its focus is the advancement of technology. They have begun to consider standards concerning cognitive radio. The IEEE sets many of the technical standards that drive the Internet revolution. IEEE-1900-B Working Group has been working on a protocol that can be transmitted to CRs. This protocol will enable networks to optimize behaviors and co-exist with other radio systems. The standard is intended to protect and certify the authenticity of the data and data privacy among other things.

4. Future of Cognitive Radio

The goal of regulatory bodies like the FCC when regulating natural resources, like the electromagnetic spectrum, is to promote its usage that is beneficial to the public at large. Intent aside, their regulations are certain to have an impact on the development of CR. The FCC and the Spectrum Policy Task Force (SPTF) are responsible for large and small paradigm shifts in the world of spectrum management. The SPTF is active in all aspects of the development of CR from operations to etiquette and protocol, and their actions significantly affect the progression and development of CR [11].

Regulations imposed by the FCC and SPTF are in the heart of the modern CR debate. There are extremists who believe in the complete liberalization of licenses, and there are those pushing for more regulations to strengthen the positions of the license holders. Although they differ on the means, both extremes are for the growth and development of CR.

Under the heavily regulated school of thought, it is believed strict standardizations and protocols are necessary for a multitude of radios to co-operate and function as a network. Standards set forth by the IEEE are deemed necessary to establish a regulatory framework that will encourage research and development rather than stifle it [15]. Ultimately, the regulations will provide a roadmap for the developers of CR, and promote growth that would not have happened were the regulations not in place.

On the other hand, many claim the liberalization of regulations will free bandwidth in the spectrum and allow for greater research. Government agencies have already allotted frequencies to license holders, and even those that call for extreme liberalization agree a certain level of licensing restrictions are necessary to maintain a healthy degree of standardization [15].

A study released in 2007 by Ofcom, the regulatory communications body of the United Kingdom, agreed with the FCC's and Irish Commission for Communications Regulation's (ComReg) assessment of the benefits of regulations on the growth of CR. They determined economic incentives to licensees coupled with standardizing policies would be the best combination motive and assist developers. Most agencies agree a compromise is crucial to the evolution of CR. Regulatory bodies are moving to reach middle-ground to direct CR into mainstream wireless communications. With enough collaboration, experts agree intelligent and auto-reconfigurable CRs will emerge in the next five years [15]. This would not be possible without the standardization of licenses and framework established by regulatory bodies such as the FCC and IEEE.

4. Conclusion

As discussed CR has the ability to learn from past behaviors and adapt itself to its surroundings. As this technology grows and develops, it will efficiently and intelligently make use of the spectrum while protecting license holders. While regulations offer a framework for CR developers, excessive regulation can hinder its development. Therefore, the fate of CR is in the policy makers' hands, and if they want to see the technology grow and develop, they must strive for regulations that respect the rights of both parties.

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