Cognitive Radio Systems: A Network Technology Assessment

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Key points

- **The rising demand and fixed supply of radio spectrum have created a spectrum crisis in the United States and an opportunity for agile radio technologies.**
- **Cognitive Radios are systems of multiple technologies (software defined radios, databases, and machine learning) and their added value is derived from this integration.**
- **The primary functions of cognitive radios are dynamic spectrum allocation using spectrum sensing to detect and negotiate usage of incumbent spectrum.**
- **Cognitive radio systems are just one category on a fluid continuum of "smart" radio technologies. As such, watch for exaggerations of capabilities from vendors claiming "intelligence" in less advanced products.**
- **The largest potential lies in technologies that take advantage of low hanging fruit in niche markets and remote locations where policy conflicts and complexity of implementation are reduced.**
- **Because of incumbent resistance to share their spectrum resources, expect adoption of cognitive radio systems on a wide scale to be slow in the next five years.**

Image 1. Cognitive Radio Systems: One radio dynamically shifts to different types of service (Fette, 2003).

The Spectrum Crisis

Key point: The rising demand and fixed supply of radio spectrum have created a spectrum crisis in the United States and an opportunity for agile radio technologies.

The US Government and the FCC have announced a crisis in the amount of radio spectrum available to providers of advanced wireless data service. New wireless applications that require high speed data transmission have lead to increased demand for spectrum. **Wireless IPTV** (in which TV programming is transmitted to cellular phones), Vehicle Asset Tracking and Control, Smart Grid for Utilities, transportation and private companies are all applications or consumers of these services (Hamilla, 2010). To take just one of these, in 2008, the worldwide IPTV customer base was estimated at 57 million users, mostly in Japan and South Korea with only 100,000 users in the Unites States. Since 2008, the U.S. market for mobile TV, and thus wireless data transmission, is expected to grow very quickly as AT&T, with over 71 million users, and its competitors' customers adopt technologies that require large amounts of data (O'Brien, 2008).

As a result the wireless industry needs 800 megahertz of more spectrum over the next six years to serve the needs of growing high speed data and telephony services. FCC Chairman Genachowski has asserted that TV broadcasters are only using 36 of 300 MHz allocated in small markets with less than 1 million people. In large markets they are using 100 to 150 of the 300 megahertz allocated (Reuters, 2010). In dealing with the crisis, the FCC has outlined a mix of policy-oriented and technical mechanisms to reduce wasted spectrum (Hamilla, 2010).

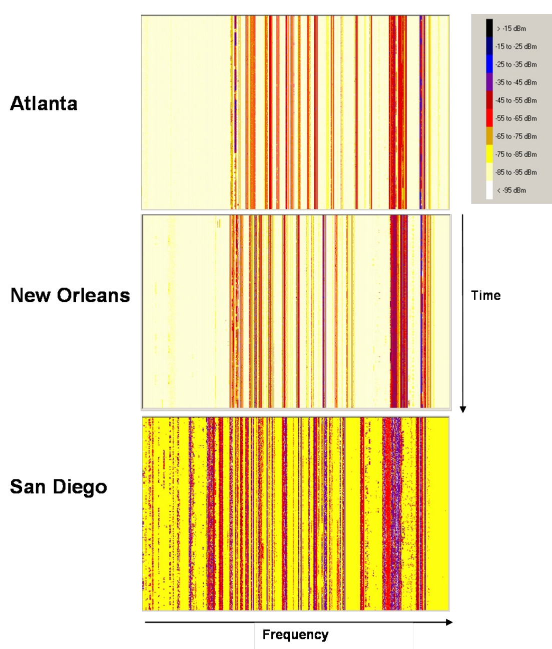

Image 2: Spectrum use in practice: some is used intensely while others are idle. (VanWazer 2003)

Cognitive Radio Systems Defined

Key point: Cognitive Radios are systems of multiple technologies (software defined radios, databases, and machine learning) and their added value is derived from this integration.

Idle spectrum is a reality of terrain and population density variations. One solution is to allow agile and opportunistic use of spectrum that would put the idle spectrum to use. **Cognitive radios** can enable flexibility in the use of one radio over multiple frequencies allowing secondary users to use a primary user's frequency spectrum in a dynamic way when it is idle. This technical solution works in concert with market and policy-oriented mechanisms that allocate this "secondary market" spectrum in ways that protect the primary users (Marcus, 2010).

The IEEE Working Group 1900.1 has a draft definition of Cognitive Radio:

- Radio in which communications systems are aware of their environment, internal state, and location and can make decisions about their radio operating behavior based on that information.
- Cognitive radio, as defined in the first, that utilizes software defined radio, and other technologies to autonomously adjust its behavior or operations to achieve the desired objectives.

(Prasad, 2008)

In taking apart the first bullet, Cognitive Radios know where they are and know what services are available, for example, it detects empty spectrum that can be used. It knows what spectrum or services are useful for the user at what degree of need, and it knows how to locate these services. The Cognitive Radio learns and recognizes the usage patterns of the users and applies model based reasoning about user needs (Fette, 2003).

Since this goes beyond the traditional function of a radio by adding "awareness" to the traditional functions of signal transmission, some are now adding the term "systems", calling them cognitive radio systems. (Prasad, 2008) As defined above, the underlying radio technology is based on **software defined radio (SDR)**, also known as software radios or programmable radios. You can program the features of an SDR instead of using hardware that is pre-designed for operation on certain frequencies. Thus they can program the frequency, power, modulation, multiplexing, signal direction and MAC protocol. Key technologies of the SDR are tunable analog filters and multiple antenna management. (Comer p.288 – 289)

When combined in a network, this technology has also been called **cognitive functionality in a wireless communication network (CFWCN)**. Implementation of cognitive functionality is the use of multiple layers of the communication network to optimize use of spectrum. Implementation includes multiple issues including policy, technical and regulatory issues (Prasad, 2008).

How do CRS work?

Key point: The primary functions of cognitive radios are dynamic spectrum allocation using spectrum sensing to detect and negotiate usage of incumbent spectrum.

A CFWCN uses automated **dynamic spectrum allocation** system for the efficient use of bandwidth within a wireless network based on user specified priorities, network environment and available network assets. This is a database driven network making real time spectrum allocations. It is based on an exchange system transacting spectrum and bandwidth through the network to the highest priority user. The network performs dynamic allocation of all customer resources including licensed and unlicensed spectrum, radio equipment and network assets. (Hamilla, 2010)

Cognitive radios have the following components. A sensing block and a policy block determine the availability of spectrum and also drive the learning and reasoning functions. These functions together are called **spectrum sensing**, they find "holes" in the spectrum where it is not being used and fills the holes with the signals. It also detects interference and kills it if needed. (Nirenberg, 2010) The implementation of cognitive radios will be aided by **cyclostationary detectors** that can detect spectrum use at much lower levels. These stations can be installed in fixed locations and may help to eliminate the hidden node problem that may occur when sharing an incumbent's spectrum. (Marcus, 2010)

Learning and decision blocks are implemented with fuzzy logic or neural networks. The decision database, along with input from the sensing and policy block, drives learning. (Prasad 2008)

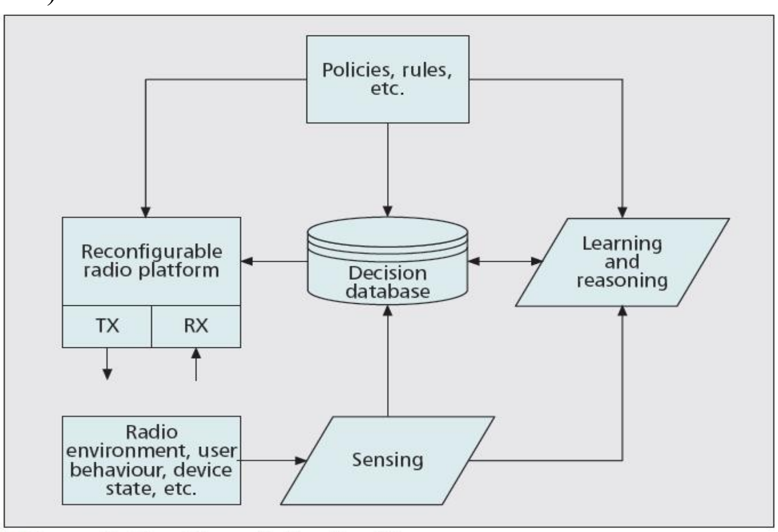

Image 3: CRS functionality (Prasad, 2008).

CRS compared with other related technologies

Key point: Cognitive radio systems are just one category on a fluid continuum of "smart" radio technologies. As such, watch for exaggerations of capabilities from vendors claiming "intelligence" in less advanced products.

Because cognitive radio systems are built on multiple technologies including software defined radios, databases, machine learning and others, they have many similarities with previous generations of radios that have attempted to share spectrum in the past. There are existing cases of spectrum sharing technology in the market that are not as complicated, meaning they have pre-determined or policy-based rules (Prasad, 2008). Some examples of these previous generations are Wi-Fi, trunk radio and **Unlicensed National Information Infrastructure (U-NII),** all of which use only small fractions of available idle spectrum (Marcus, 2010).

Because implementing a cognitive radio system requires negotiation of policy and market mechanisms, adoption may be slower than if the solution were purely technical. Some industry experts suggest companies should go for the low hanging fruit and implement spectrum sharing radios where the secondary user is weak, where there are large holes for long durations, when you don't need a lot of coordination and computation. Then build more complexity into it. (McHenry, 2003) This would mean the radios may not be "cognitive" but will be close to it.

Type of radio	Platform	Reconfiguration and adaptability	Intelligence
Hardware	Hardware	Minimal	None
Software	Hardware/software	Automatic	Minimal
Adaptive	Hardware/software	Automatic/predefined	Minimal/none
Reconfigurable	Hardware/software	Manual/predefined	Minimal/none
Policy-based	Hardware/software	Manual (database)/automatic	Minimal/none
Cognitive	Hardware/software	Full	Artificial/machine learning
Intelligent	Hardware/software	Full	Machine learning/use of prediction for decision

Table 1. *Comparison of different types of adaptive radio devices.*

(Prasad, 2008)

Opportunities and Risks for Future CRS Implementations

Key point: The largest potential lies in technologies that take advantage of low hanging fruit in niche markets and remote locations where policy conflicts and complexity of implementation are reduced.

Starting with the lowest hanging fruit, wireless providers now see a market in niche areas that need more flexibility in radio spectrum. TerreStar is a satellite communications company that has recently launched a mobile product that combines satellite and cellular communication onto one smart phone. TerreStar has recently signed a contract with AT&T to provide cellular communications and will use its own satellite to provide backup communications with the user is in a remote area or if cellular communications are clogged. Their handsets will be built with software defined radios that will enable both types of communication. Potential markets for these versatile phones are outdoor enthusiasts, local emergency first responders, and transportation companies (Stern, 2010).

As mentioned above the opportunities for agile radio technologies like cognitive radio systems are directly linked to the growing market for wireless data transmission as 3G applications grow to 4G. However, in order to make large amounts of spectrum available to wireless carriers, the FCC must get involved to convince incumbent users of spectrum to engage in sharing schemes like a secondary market. However, lobbying groups for the incumbents warn of harmful interference to their spectrum. Wireless innovators claim the incumbents are engaging in "abuses of process" to wear down secondary users with fewer resources by using bureaucratic methods.

Key point: Because of incumbent resistance to share their spectrum resources, expect adoption of cognitive radio systems on a wide scale to be slow in the next five years.

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