Spectrum Regulations for Ad Hoc Wireless Cognitive Radios

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INTRODUCTION:

Utilizing cognitive dynamic spectrum access in ad hoc networks can increase the amount of spectrum available to these networks thereby improving communications performance and spectrum efficiency. Researchers such as those involved in the DARPA Next Generation (XG) Communications program hope that by using underutilized spectrum cognitive radio will provide a 10 times spectrum capacity improvement. (1).

Potential users of cognitive ad hoc wireless LAN/MAN technologies include public safety, military, homeland defense, and commercial wireless organizations. This paper identifies for these users the US domestic and international spectrum regulatory issues requiring attention. One instance of dynamic spectrum access that has been incorporated into national and international spectrum regulations is Dynamic Frequency Selection (DFS). Wireless broadband access devices implementing Dynamic Frequency Selection (DFS) must detect the presence of other devices on a channel and automatically switches the devices to another channel when such devices are detected. Today (2005) regulations exists that require certain wireless broadband access devices to implement DFS services in the 5 GHz spectrum(2).

Regulatory changes should be evolutionary starting at a national/regional level (e.g. US and Europe) and move to a global basis. The paper is directed to an identification of a number of regulatory alternatives.

DEFINITIONS

First we define cognitive radio and ad hoc networks. No specific Radio Regulation either domestically in the US or internationally has defined cognitive radio. Working Part 8A of the ITU-R in a Draft New Report on Software Defined Radio (SDR) tentatively defines cognitive radio as "*A*

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[1] * The views and opinions of the authors expressed herein do not necessarily state or reflect those of Alion Science and Technology or its clients and sponsors.

radio or system that senses, and is aware of its operational environment and can be trained to dynamically and autonomously adjust its operating parameters accordingly".

Now turning to mobile ad hoc networks they can be defined as self-organizing peer-to-peer networks of mobile stations operating without the control of a centralized access point. Each node independently determines access and the usual access protocol is Carrier Sense Multiple Access (CSMA). Nodes coordinate amongst themselves locally to determine channel access. An important parameter for spectrum management is the number of neighbor nodes a given node must have a connection with for the network to be successful. The number of connected nodes along with frequency reuse distances determines the number of channels needed for the network. In general, it is agreed that ad hoc wireless networks require each node to be connected to 6-8 neighbors. This is a subject of active study [3].

Ad hoc transmitting sources are often times not line of sight to their intended receiver. Instead, other nodes relay packets of information in order to send data across a network. A diagram illustrating multi-hop routing in an ad hoc network is shown in Figure 1. The message from A is communicated to B by hopping between nodes C, D, E F and G

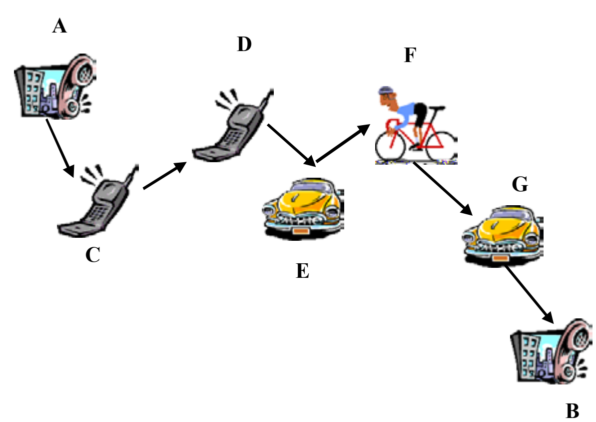

Figure 1 Packet relay of a message

REQUIREMENTS FOR COGNITIVE RADIO

Currently, the Department of Defense's (DoD's) transformation to network centric warfare is increasing the need for radio spectrum and the adoption of new techniques such as cognitive radio and software defined radio (SDR). Cognitive radio and SDR may provide ways to increase the amount of information that can be communicated over the currently available spectrum. DoD wireless network initiatives such as the Joint Tactical Radio System (JTRS), Wideband Networking Waveform (WNW) and Soldier Radio Waveform (SRW) must coexist with many other military and civil systems which limit spectrum availability. Additionally, the DoD has the requirement for communication in geographical areas (for example urban environments) which already include both cooperative and non-cooperative existing operations. The DoD organization most involved in developing cognitive radio as a potential solution to these problems is the DARPA XG program (1). The DARPA XG program hopes to create technologies that can increase by a factor of 10 or more DoD's ability to efficiently utilize spectrum. The vision is for the XG enabled radios to automatically select spectrum and the operating mode that will minimize disruption of existing users while ensuring the operation of US systems in a battlefield environment.

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After considerable technical studies and planning the XG program is now entering a demonstration phase and hopes to demonstrate the capability of a cognitive radio system to detect other transmitting devices and adapt its behavior to avoid interference to these other devices [4].
The demonstrations will take place in over-the-air environments that will include Federal Government-owned range(s) and one or more urban areas. The demonstrations will exercise prototypes in spectrum bands between 30 MHz and 2 GHz. The demonstrations will also identify the associated spectrum-use policies and provide rationale for their selections.

To date, the most ambitious deployment of a cognitive radio system is the Canadian deployment of the Project MILTON (5). The MILTON Network is a wireless network that continually senses the radio environment and responds to physical, electrical and regulatory requirements. As early as 1997 Canada had the need for community broadband wireless Internet in remote areas and the Canadian Research Centre in Ottawa began in 1997 propagation studies of the possible use of the 5 GHz unlicensed spectrum for cognitive radio.

REGULATION CONCEPTUAL OVERVIEW

Regulations for cognitive radio should specify constraints for coexistence between competing systems but not specify the implementation techniques. The implementation should be left to radio and protocol designers to specify. For example the regulations should not specify a particular waveform to be used. The regulatory constraints should be kept to a minimum to allow flexibility in operation. The ad hoc wireless cognitive radios can operate any way they want as long as they abide by the rules for coexistence. For example an issue needing study is whether control of the network should include control channels or beacons. This should not be included in the Regulations but the system implementer makes the decision on how the network is operated. Also it is necessary that the radios adhere to the regulations (compliance) which should be verified by testing.

A CASE STUDY ON REGULATION DEVELOPMENT-5 GHZ RADAR SHARING WITH UNLICENSED WIRELESS ACCESS SYSTEMS

A good precedence for how the regulatory development should proceed for cognitive radio is the WRC-03 allocation of wireless access systems (domestically denoted as unlicensed operations) in the 5 GHz band. At WRC -03 the regulatory community agreed on a method for 5 GHz spectrum sharing of radar and wireless access systems. The basis for the sharing was agreement on the use of Dynamic Frequency Selection in 5230- 5350 MHz and 5470-5725 MHz. The specific sharing method which includes Recommendation ITU-R M 1652 Annex 1.
These additional criteria are:

- maximum signal levels and EIRPs for wireless access systems (unlicensed devices)
- listen before transmit (CSMA)
- Monitoring for the presence of radars between transmissions
- maximum duration of 10 seconds after which transmission must cease if an occupying radar signal is detected

- minimum of 30 minutes before the wireless access system can attempt to reoccupy the channel vacated by the radar operation

Taking this a bit further, a good model of how specific sharing criteria might be developed for cognitive radio is that approved by the FCC in the US for this 5 GHz sharing situation, The specific sharing criteria follow. These are taken verbatim from the FCC rules (47 C.F.R. §15.407) for unlicensed national information infrastructure (U-NII) devices.

(ii) Channel Availability Check Time. A U-NII 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 non-occupancy period starts at the time when the radar system is detected.

Let us now interpret these FCC regulations. Figure 2 shows the meaning of these regulations.

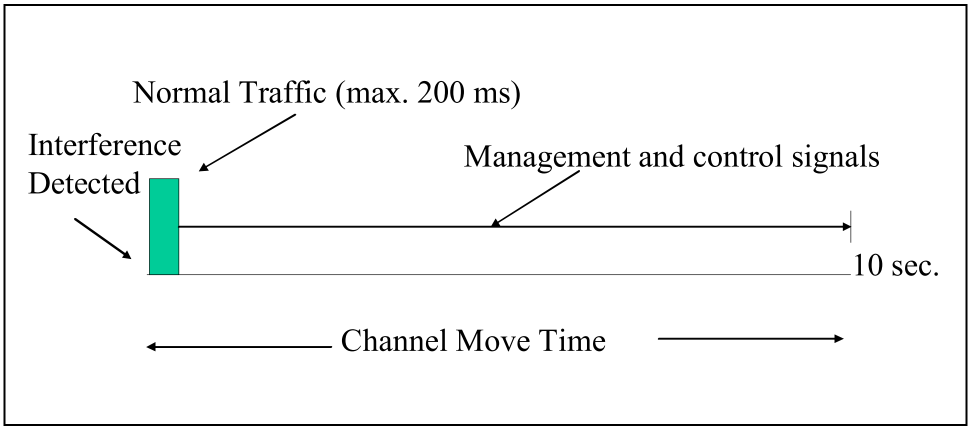

Figure 2 Discrete Frequency Selection for Radar and Unlicensed Operations

Note from the Figure 2 the node can send normal traffic for a maximum period of 200 ms after detection of the radar signal. During the remaining time period of 10 seconds intermittent management and control signals can be sent. This gives the cognitive radio system adequate time to determine (i.e. use DFS) and move to the new spectrum channel location. How it does this is up to the network designer to implement and not contained in the regulations.

Note also that the IEEE is even more lenient in its move time requirement and in its response to the FCC 03-287 [6] that the specifying the condition for detection of the primary radar signal occupancy is likely to be implementation dependent and need not be codified in the FCC rules. It stated that allowing this flexibility would avoid constraining the future development of innovative approaches that may provide superior performance.

REGULATION ALTERNATIVES

Below we list with comment regulatory issues needing review for cognitive radios:

A. *Machine Readable Policies* There is a need for regulatory community acceptance (both national and international) of the principle that mobile transceivers may download radio regulations in a standard machine readable format (both allocations and spectrum sharing technical parameters) and use these downloads as a basis for accomplishing cognitive radio spectrum sharing. Also identify for inclusion in the software the sharing criteria that cognitive radios would adhere to for particular geographic locations and allocated bands. This will require that spectrum regulation is written in such a way that it can be interpreted by the radio and that the radio is able to exploit such regulation [1]

B. *Acceptable Interference* With cognitive radio it is possible that interference (probably not harmful interference) will occur when the primary system communication commences. This needs to be an agreed assumption in any regulatory scheme for cognitive radio. It is implicit in the already agreed 5 GHz radar unlicensed sharing.

C. *Allocation Footnotes and Rules for Spectrum Use*. One rule set could specify discrete frequencies and bands that must be avoided under all conditions (e.g. distress and safety channels, Radionavigation). Also in orbit uplink Fixed Satellite bands should be avoided since the cognitive radios may as an aggregate have an interference effect on in orbit Fixed Satellite receivers.

D. *Protection from Inteference* Cognitive radios should have no protection from interference in the traditional sense. An obvious regulation alternative since cognitive radio can adapt to the spectrum environment.

E. *Flexibility in Service Definitions*. Current allocations are made on a detailed service level basis making specific distinctions between mobile and fixed. The distinction between radiocommunications services blurs with multifunction devices that send information (voice, video, data, geolocation etc.) as bits. These traditional service definitions may not be appropriate since cognitive radio devices can share spectrum with like and dissimilar systems. Indeed, with the move to more flexible spectrum use there is a need to reduce the number of service definitions.

F. *Security Requirements* need additional regulatory language for anti-tampering, authentication, privacy, and other security requirements? Already work was accomplished by the FCC [7]. It is not a focus of this paper.

G. *More Unlicensed Spectrum Allocations*-Increased spectrum allocations are required for unlicensed use both nationally and internationally. Unlicensed spectrum is ideal for cognitive radio. Note however that the unlicensed bands are subject to congestion and laissez-faire operation. Indeed, [8, Section 5.3.3] makes note, "that in the world of dynamic spectrum access (DSA) there may be spectrum hogs who may monopolize the spectrum to the exclusion of others." A further look at the regulations and monitoring of unlicensed spectrum may be needed. Keeping this in mind cognitive radio for Public Safety and DoD applications may wish and need to operate in licensed bands where there is more orderly use of the spectrum.

H. *Unlicensed Sharing of Unused TV Channels and the "3650 MHz Band"* – Another possible use of cognitive radio may be to identify unused TV channels by spectrum sensing techniques and location technologies such as GPS. (9) This would provide an opportunity for the development and use of new unlicensed wireless communications and more efficient use of the TV spectrum. Another possibility is permitting unlicensed operation in the 3650 MHz band using a DFS like mechanism which would listen for FSS earth station uplink signals (10).

I. *Specification of Minimum Signal Levels*. In the FCC rules (47 C.F.R. §15.407 (h)) minimum DFS detection thresholds are specified. to detect the presence of radar interference. Some systems have some very low minimum signal and include satellite communications, weather radio, GPS and the weakest are passive services such as radio astronomy. Can one minimum signal level value suffice for this in all sharing of DFS with other equipments or does it depend on each individual situation.

J. *Use of Heteromorphic Waveforms (e.g.* Orthogonal Frequency Division Multiplexing OFDM). Heteromorphic waveforms can morph to utilize gaps in the spectrum based on the parameters time, space, frequency, data rate, and other characteristics to increase spectrum capacity density and thus improve spectrum efficiency. [10]

K. *Worst Case Analyses* Currently system planning is done based on worst case analyses to demonstrate non-interference to an incumbent system. Worst case analyses and scenarios may not be appropriate for cognitive radio and new regulatory text may need to be written for cognitive radio system planning. In particular for the NTIA Manual Chapter 10 and possibly other regulatory texts such as international ITU-R Recommendations new text may need to be added for system planning of cognitive radio. Eventually, possibly the ITU Radio Regulations will need additions.

L. *Experimental Allocations* Consider experimentally restrict in an allocated band a small portion of the band (e.g. 10%) for testing of cognitive radio. This would likely first be done in the US or Europe to prove the feasibility of cognitive radio. Candidate bands may be the 10 MHz bands identified in the President's Spectrum Initiative test bed. [11]

TESTING OF UNLICENSED COGNITIVE RADIO SYSTEM INTERFERENCE ON METEORLOGICAL RADAR

The latest WRC-2003 allocation for wireless access systems use in the 5250-5350 MHz and 5470- 5725 MHZ is under consideration in Canada for unlicensed "last mile" solutions in rural and remote areas for Internet access. Applications may include real time transfer of video files, CD files, digitized voice and high data content information.

Canada to help decide its regulatory implementation of this ITU WRC-2003 allocation recently performed testing of the impact of wireless access DFS systems on Meteorological Radars (12) The Canadian tests concluded that (a) the DFS would detect the radar sooner than the wireless access system would corrupt the radar and (b) the degradation to the radar is related to the mean amount of interference power and a mean power of –79 dBm is the threshold for reflectivity degradation.

INTERNATIONAL PERSPECTIVE

Currently changes to the International Radio Regulations occur roughly with a lead time of 5-10 years. Thus changes to the International Radio Regulations are evolutionary rather revolutionary. The topic of modernization of spectrum management is not on the agenda for WRC-07. This is unfortunate for new allocation concepts such as cognitive radio which fit in this topic area. The WRC process needs speeded up for new technologies such as cognitive radio but how this can be accomplished is any one's guess.

There exists a current international regulation, Article 4.4 that provides some support for cognitive radio. Article 4.4 states: Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, *except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution,* the Convention and these Regulations."
The ITU-R Recommendation ITU-R M 1652 Annex 1 discussed earlier permits a cognitive radio to stay for ten seconds on a channel before it moves off. This implicitly assumes that during this 10 second period it is not causing harmful interference and thus can be interpreted as an action in accordance with Article 4.4 of the International Regulations.

CONCLUSIONS

Initial regulatory action in support of cognitive radio took place in the 5 GHz sharing of radar and unlicensed. This does establish precedence.

At present cognitive radio is not well enough defined to adopt specific spectrum management regulations. The DoD is currently undertaking the proof of concept [1] utilizing prototypes and demos.

Specific regulations can be adopted after a successful demonstration of these cognitive radio prototypes and demos. It is recommended that the NTIA and FCC should encourage the implementation of cognitive radio testing and prototypes. After proof of the cognitive radio concept the NTIA and FCC should institute domestic regulations and support international adoption of cognitive radio techniques. It is hoped that the European spectrum management community will also conduct proof of concept demos and afterwards adopt spectrum regulations in support of cognitive radio.

The DoD has a significant need for cognitive radio to meet its long term operational communication goals. It will, after completion of the proof of concept, need to take the initiative for the spectrum management community on spectrum support for cognitive radio.

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