Cognitive Radio Networks for Wireless Communication

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***Abstract*-The world of wireless communications is nowadays facing a serious problem of spectrum shortage. Such problem is not only due to"real" limitations on the available bandwidth, but also (and mainly) to inefficient policies in spectrum management. Indeed, today's wireless networks are characterized by a fixed spectrum assignment policy, which often leads to waste large spectrum portions due to sporadic utilization by the licensed users. The recentadvances in the field of software defined radios are pushing forward a novel networking paradigm where all the users or part of them access the spectrum in an opportunistic way. Acommon cognitive radio network model features the presence of primary (or licensed) users who have priority access to the bandwidth, whereas secondary users can accessthe bandwidth only when vacated by the primary ones. Moreover, the strict constraint for the secondary users is not to harm primary users' transmissions.**

Keywords-Full Cognitive Radio, Spectrum Sensing Cognitive Radio, Licensed Band Cognitive Radio, Unlicensed Band Cognitive Radio

I. Introduction

The idea of cognitive radio was first presented officially by Joseph Mitola III in a seminar at KTH, The Royal Institute of Technology, in1998, published later in an article by Mitola andGerald Q. Maguire, Jr in 1999. [1] It was a novelapproach in wireless communications that Mitolalater described as:The point in which wireless personal digitalAssistants (PDAs) and the related networks aresufficiently computationally intelligent aboutradio resources and related computer-tocomputercommunications to detect usercommunications needs as a function of usecontext, and to provide radio resources andwireless services most appropriate to thoseneeds.It was thought of as an ideal goal towards whicha software-defined radio platform should evolve:a fully reconfigurable wireless black box thatautomatically changes its communication variables in response to network and user demands. Regulatory bodies in various countries (including the Federal Communications Commission in the United States and Ofcom in the United Kingdom) found that most of the radio frequency spectrum was inefficiently utilized. For example, cellular network bands are over loaded in most parts of the world, but amateur radio and paging frequencies are not. Independent studies performed in some countries confirmed that observation, and concluded that spectrum utilization depends strongly on time and place. Moreover, fixed spectrum allocation prevents rarely used frequencies (those assigned to specific services) from being used by unlicensed users, even when their transmissions would not interfere at all with the assigned service. This was the reason for allowing unlicensed users to utilize licensed bands whenever it would not cause any interference (by

Avoiding them whenever legitimate user presence is sensed). This paradigm for wireless communication is known as cognitive radio.

Depending on the set of parameters taken into account in deciding on transmission and reception changes, and for historical reasons, we can distinguish certain types of cognitive radio. The main two are Full Cognitive Radio("Mitola radio"): in whichevery possible parameter observable by aWireless node or network is taken into account.

Spectrum Sensing Cognitive Radio: in whichonly the radio frequency spectrum is considered.Also, depending on the parts of the spectrumAvailable for cognitive radio, we can distinguish:

Licensed Band Cognitive Radio: in whichcognitive radio is capable of using bandsassigned to licensed users, apart from unlicensed mbands, such as U-NII band or ISM band. TheIEEE 802.22 working group is developing astandard for wireless regional area network(WRAN) which will operate in unused televisionchannels.

Unlicensed Band Cognitive Radio: which canonly utilize unlicensed parts of radio frequencyspectrum. One such system is described in theIEEE 802.15 Task group 2 specification. Whichfocuses on the coexistence of IEEE 802.11 andBluetooth.

II. Technology

Although cognitive radio was initially thought of as a software-defined radio extension (Full Cognitive Radio), most of the research work is currently focusing on Spectrum Sensing Cognitive Radio, particularly in the TV bands. The essential problem of Spectrum Sensing Cognitive Radio is in designing high quality spectrum sensing devices and algorithms for exchanging spectrum sensing data between nodes. It has been shown that a simple energy detector cannot guarantee the accurate detection of signal presence, calling for more sophisticated spectrum sensing techniques and requiring information about spectrum sensing to be exchanged between nodes regularly. Increasing the number of cooperating sensing nodes decreases the probability of

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false detection.[12] Filling free radio frequency bands adaptively using OFDMA is a possible approach. Timo A. Weiss and Friedrich K. Jondral of the University of Karlsruhe proposed a Spectrum Pooling system[5] in which free bands sensed by nodes were immediately filled by OFDMA sub bands. Applications of Spectrum Sensing Cognitive Radio include emergency networks and WLAN higher throughput and transmission distance extensions. Evolution of Cognitive Radio toward Cognitive Networks is under process, in which Cognitive Wireless Mesh Network (e.g. CogMesh) is considered as one of the enabling candidates aiming at realizing this paradigm change.

III. Cognitive system

We can exploit the information from physical and link layer to help routing protocol in making various routing decisions. By exploiting radio layer information routing protocol can: Differentiate routes depending on channel type due to changing propagation characteristics of various radio links. This leads to better QoS when compared to algorithm taking into account number of hops only. Increase nodes connectivity due to wider set of available radio links andavailable longer transmission distances: any cognitive radio node is capable of transmitting with broad set of frequencies, i.e. UNII and USM band [4] or UNII, USM and TV band [1]. By utilizing simple measure that the higher the frequency the shorter the transmission distance, routing algorithm may decide which radio link should be used for specific hop. It has very important implications to emergency network since high frequency signals have bigger problems with thick objects penetration. It is why routing has to utilize the channel information and send high priority packets on highly resilient channels (lower frequency channels).

· Detect faster link failures.

· Perform more efficient multicast due to increased connectivity.

IV. Cognitive radio system

It is already known that physical and data link layer protocols designed for standard fixed bandwidth ad hoc networks must be changed and adapted to cognitive radio environment to effectively utilize spectrum information. The role of those modified layers of the protocol stack is to manage radio resources in the way appropriate for the nodes in the whole CRN. The remaining layers might be adapted explicitly to cognitive radio networks. Indeed in authors claim that higher layers [above link layer] will implement standard protocols not specific to cognitive radios. However it is valuable to examine in the AAF project the impact of cognitive radio capabilities on routing protocols in ad-hoc networks (application layer is beyond the scope of the AAF project). Especially the project should answer the question what is the benefit for routing protocols from introducing cognitive capabilities to network nodes in terms of:

- Time constraints: route setup time and end-to-end latency;
- Casting issues (multicast, broadcast, geocast and unicast);
- Throughput: overhead value, overall transmitted traffic value, packet loss value;□
- Route quality: route length, route discovery and reconstruction time.

V. Main functions

The main functions of Cognitive Radios are:
Spectrum Sensing: detecting the unusedspectrum and sharing it without harmfulinterference with other users, it is an importantrequirement of the Cognitive Radio network to sense spectrum holes, detecting primary users isthe most efficient way to detect spectrum holes.Spectrum sensing techniques can be classifiedinto three categories:
Transmitter detection: cognitive radios musthave the capability to determine if a signal froma primary transmitter is locally present in acertain spectrum, there are several approachesproposed:

- matched filter detection
- energy detection
- cyclostationary feature detection
- Interference based detection

*Cooperative detection:*refers to spectrumsensing methods where information frommultiple Cognitive radio users are incorporatedfor primary user detection.
Spectrum Management: Capturing the best available spectrum to meet user communication requirements. Cognitive radios should decide on the best spectrum band to meet the Quality of service requirements over all available spectrum bands, therefore spectrum management functions are required for Cognitive radios, these management functions can be classified as:

- Spectrum analysis
- Spectrum decision

Spectrum Mobility: is defined as the process when a cognitive radio user exchanges its frequency of operation. Cognitive radio networks target to use the spectrum in a dynamic manner by allowing the radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during the transition to better spectrum
Spectrum Sharing:providing the fair spectrum scheduling method, one of the major challenges in open spectrum usage is the spectrum sharing. It can be regarded to be similar to generic media access control MAC problems in existing systems

VI. Cognitive radio (CR) versus intelligent antenna (IA)

Intelligent antenna (or smart antenna) is antenna technology that uses spatial beam forming and spatial coding to cancel interference; however, it requires intelligent multiple or cooperative antenna array. On the other hand, cognitive radio (CR) allows user terminals to sense whether a portion of the spectrum is being used or not, so as to share the spectrum among neighbor users. The following table compares the different points between two advanced approaches for the future wireless systems: Cognitive radio (CR) vs. Intelligent antenna (IA).

Point	Cognitive radio (CR)	Intelligent antenna (IA)
Principal goal	Open Spectrum Sharing	Ambient Spatial Reuse
Interference processing	Avoidance by spectrum sensing	Cancellation by spatial pre/post-coding
Key cost	Spectrum sensing and multi-band RF	Multiple or cooperative antenna arrays
Challenging algorithm	Spectrum management tech	Intelligent spatial beam forming/coding tech
Applied techniques	Cognitive Software Radio	Generalized Dirty-Paper and Wyner-Ziv coding
Basement approach	Orthogonal modulation	Cellular based smaller cell
Competitive technology	Ultra wideband for the higher band utilization	Multi-sectoring (3, 6, 9, so on) for higher spatial reuse
Summary	Cognitive spectrum sharing technology	Intelligent spectrum reuse technology

Intelligent antenna (IA) is antenna technology which exploits electronic intelligence to enhance the performance of radio communication systems, as well as being used to enhance the performance of free band systems. For instance, IA-based multiple antenna terminals enable to communicate multiple radio links simultaneously up to the number of embedded multiple antennas.

Dirty paper coding (DPC)-pre-cancels the knowninterference signal at the transmitterwithout the additional transmit power regardlessof knowing the interference at the receiver,which can be used to optimize cognitive wireless network channels.

VII. Security

One of the factors which should be considered during design process of CRN emergency network is security of the network infrastructure and security of transmitted information. Without proper network security terrorists responsible for the disaster would beable to eavesdrop emergency information and utilize it for future attacks. Moreover the network elements due to their poor security could become a target of attack itself. Because cognitive radio constitute a new approach for building wireless networks it simultaneously opens a door for new methods of attacks on their physical structure. Below we outline some of the possible methods of attacks on CRN and ways of prevention:

Licensed user emulation attack: Because cognitive radios cannot be completely sure whether a licensed spectrum is free and available for transmission they simply defer from licensed bands and utilize other non-licensed parts of the band if they are not sure if it is really free.Suppose that attacker knows in which specific area CRN works. Knowing which licensed bands CRN might use attacker can simply transmit signal in the licensed band emulating real transmission and thus limiting overall CRN capacity. Until now wedon't know any method of prevention against this attack.

*Common control channel jamming:*One of the possible solutions for common control channel deployment is the UWB. In this case, potential attacker can simply transmit periodical pulses which have the same spectrum as common control channel of CRN but with higher power than legitimate users. Throughout jamming of just one channel attacker blocks the possibility of communication between all CR nodes. This is the reason for building sophisticated UWB transmission methods for control channels utilizing UWB. It has to be underlined that a need for special care of control channel is the same for any type of approach (dedicated channel, channel hopping etc.).

Attacks on spectrum managers: We cannot allow having one central spectrum manager responsible for assigning frequency bands for nodes (see paragraph 2.3) because it constitutes a single point of attack. Whenever the spectrum manager is not available for CR nodes the communication process becomes impossible. That is why information about spectrum availability should be as distributed and replicated as possible. This constraint is in line with the requirement for more accurate measurements of spectrum availability. One of the preventing ways for this attack is to use specific pilot channel in each license band. It would inform secondary users about the reservation of the nodes.

Eavesdropping:Usually in the infrastructure-based corporate WLAN it was assumed that signal will not leavebuilding due to his short distance and will be limited to eavesdropping and sniffing. However cognitive radios are allowed to work in the bands lower than UNII and ISM. This means that they can perform longer transmission distances with the same powers. It also allows for easy physical data collection from locations far distanced from CRN location where attackers invisible to emergency services. This yields a need for strong data encryption at the physical level. Frequent leaving and joining the emergency network must be preceded by authentication process. It is open for discussion which layer should be responsible for this step. Currently the most possible approach is that application layer will perform all the necessary authentication procedures. Moreover the entire WEP infrastructure should be the basis for authentication procedures in CRNs.

VIII. Conclusion

The rapidly changing radio environment, more radio channels to utilize, number of parameters to choose during decisions taken by MAC and routing protocols, etc. makes design of CRNs very challenging. In this deliverable we have outlined some specific parameters and constraints which have to be taken into consideration while designing protocols for layers above PHY. Many protocols have the same designrequirements (like robustness, no clocksynchronization or localizing capabilities)which simplify design by small fraction.Moreover we can state that UWB as aCommon control channel might become agood solution for realizing certain functionsoutlined in this document. We also outlinethat cooperation between physical and linklayer is essential for accurate operation of CRN. We have to emphasize that newrequirements might occur during designprocess so this document will be constantlyupdated.

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