Opportunistic Spectrum Access in Cognitive Radio Ad Hoc Networks

Tarek M.Salem[1], Sherine M. Abd El-kader[2], Salah M.Ramadan[3] , M.Zaki Abdel-Mageed[4]

[1] Assistant Research at Electronics Research Institute, Computers and Systems Dept, Cairo, Egypt

[2] Associate Professor at Electronics Research Institute, Computers and Systems Dept, Cairo, Egypt

[3] Associate Professor at Al-Azhar University, Computers and Systems Dept, Cairo, Egypt

[4] Professor at Al-Azhar University, Computers and Systems Dept, Cairo, Egypt

Abstract

Cognitive Radio (CR) technology is envisaged to solve the problems in wireless networks resulting from the limited available spectrum and the inefficiency in the spectrum usage by exploiting the existing wireless spectrum opportunistically. CR networks, equipped with the intrinsic capabilities of the cognitive radio, will provide an ultimate spectrum aware communication paradigm in wireless communications. Such networks, however, impose unique challenges due to the high fluctuation in the available spectrum as well as diverse Quality-of-Service (QoS) requirements. Specifically, in Cognitive Radio Ad Hoc Networks (CRAHNs), the distributed multi-hop architecture, the dynamic network topology, and the time and location varying spectrum availability are some of the key distinguishing factors. In this paper, current research challenges of the CRAHNs are presented. First, spectrum management functionalities such as spectrum sensing, spectrum sharing, and spectrum decision, and spectrum mobility are introduced from the viewpoint of a network requiring distributed coordination. Moreover, the influence of these functions on the performance of the upper layer protocols are investigated and open research issues in these areas are also outlined. Finally, the proposed tools, and best simulator to solve research challenges in spectrum management are explained. This gives an insight in choosing the suitable tool, and the suitable simulator that fit for solving different challenges.

Keywords: Cognitive radio network, Spectrum characteristics, Spectrum Selection, Spectrum sensing.

1. Introduction

The usage of radio spectrum resources and the regulation of radio emissions are coordinated by national regulatory bodies like the Federal Communications Commission (FCC). The FCC assigns spectrum to licensed users, also known as primary users, on a long-term basis for large geographical regions. However, a large portion of the assigned spectrum remains under utilized as illustrated in Fig. 1. The inefficient usage of the limited spectrum necessitates the development of dynamic spectrum access techniques [1], where users who have no spectrum licenses, also known as secondary users, are allowed to use the temporarily unused licensed spectrum.

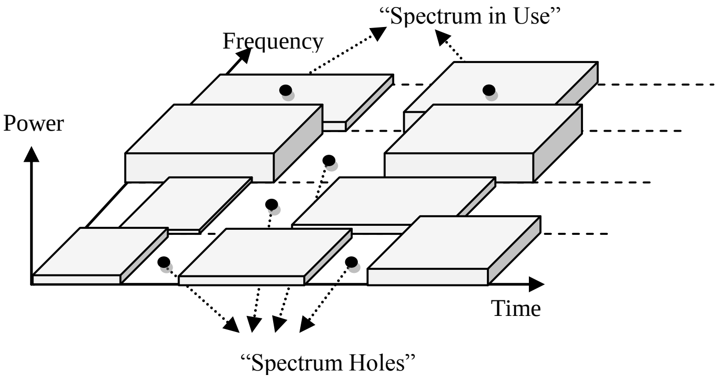

Fig. 1: Spectrum holes concept

The term "cognitive radio" was defined in [2] as follows: "Cognitive radio is an intelligent wireless communication system that is aware of its ambient environment. This cognitive radio will learn from the environment and adapt its internal states to statistical variations in the existing RF environment by adjusting the transmission parameters (e.g. frequency band, modulation mode, and transmit power) in real-time." From this definition, two main characteristics of the cognitive radio can be defined as follows:

Cognitive capability: Cognitive capability refers to the ability of the radio technology to capture or sense the information from its radio environment. This capability cannot simply be realized by monitoring the power in some frequency bands of interest but more sophisticated techniques, such as autonomous learning and action decision are required in order to capture the temporal and spatial variations in the radio environment and avoid interference to other users.

Reconfigurability: The cognitive capability provides spectrum awareness whereas reconfigurability enables the radio to be dynamically programmed according to the radio environment. More specifically, the cognitive radio

Copyright (c) 2014 International Journal of Computer Science Issues. All Rights Reserved.

can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design.

The ultimate objective of the cognitive radio is to obtain the best available spectrum through cognitive capability and reconfigurability as described before. Since most of the spectrum is already assigned, the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users as illustrated in Fig. 1.

In this paper, up-to-date survey of the key researches on spectrum management in (CRAHNs) is provided. We also identify and discuss some of the key open research challenges related to each aspect of spectrum management. The reminder of this paper is arranged as follows. A brief overview of the spectrum management framework for CRAHNs is provided in Section 2. In Section 3, Challenges associated with spectrum sensing are given and enabling spectrum sensing methods are explained. An overview of Spectrum decision for cognitive radio networks with open research issues are presented in Section 4. In Section 5, spectrum sharing for CRAHNs is introduced. Spectrum mobility and proposed tool to solve spectrum management research challenges for CRAHNs are explained in Section 6, 7 respectively. Finally, in Section 8 concludes the paper.

2. Spectrum management framework for cognitive radio network

The components of CRAHNs architecture, as shown in Fig. 2, can be classified in two groups as the primary network and the CR network components. The primary network is referred to as an existing network, where the primary users (PUs) have a license to operate in a certain spectrum band. If primary networks have an infrastructure support, the operations of the PUs are controlled through primary base stations. Due to their priority in spectrum access, the PUs should not be affected by unlicensed users. The CR network (or secondary network) does not have a license to operate in a desired band. Hence, additional functionality is required for CR users (or secondary user) to share the licensed spectrum band. Also, CR users are mobile and can communicate with each other in a multi-hop manner on both licensed and unlicensed spectrum bands. Usually, CR networks are assumed to function as stand-alone networks, which do not have direct communication channels with the primary networks. Thus, every action in CR networks depends on their local observations.

In order to adapt to dynamic spectrum environment, the CRN necessitates the spectrum aware operations, which form a cognitive cycle [3], the steps of the cognitive cycle consist of four spectrum management categories: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility. To implement CRNs, each function needs to be incorporated into the classical layering protocols, as shown in Fig. 3.

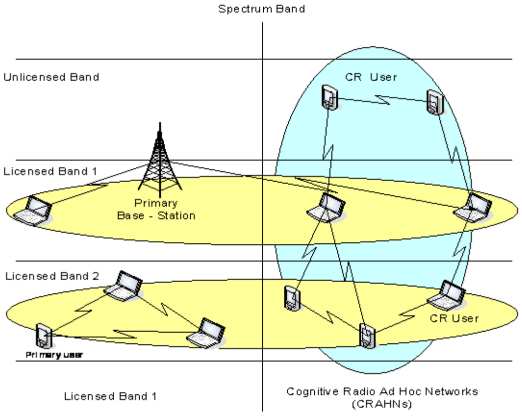

Fig. 2: The CRAHN architecture

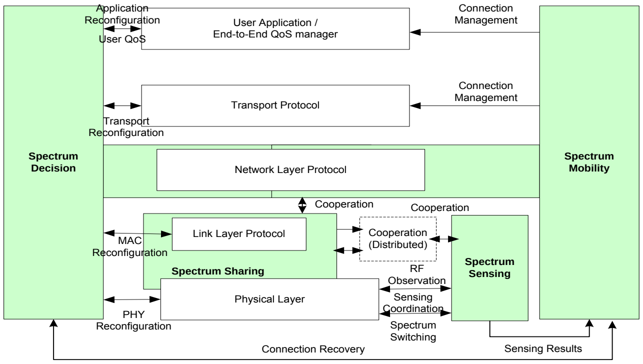

Fig. 3: Spectrum management framework for CRN

In the following sections, spectrum management categories for CRAHNs are introduced. Then, we investigate how these spectrum management functions are integrated into the existing layering functionalities in ad hoc networks and address the challenges of them. Also, open research issues for these spectrum management are declared.

3. Spectrum sensing for cognitive radio networks

A cognitive radio is designed to be aware of and sensitive to the changes in its surrounding, which makes spectrum sensing an important requirement for the realization of CR networks. Spectrum sensing enables CR users to exploit the unused spectrum portion adaptively to the radio environment. This capability is required in the following cases: (1) CR users find available spectrum holes over a wide frequency range for their transmission (out-of-band sensing), and (2) CR users monitor the spectrum band during the transmission and detect the presence of primary

Copyright (c) 2014 International Journal of Computer Science Issues. All Rights Reserved.

networks so as to avoid interference (in band sensing). As shown in Fig. 4. In the following subsections, more details about functionalities for spectrum sensing will be provided.

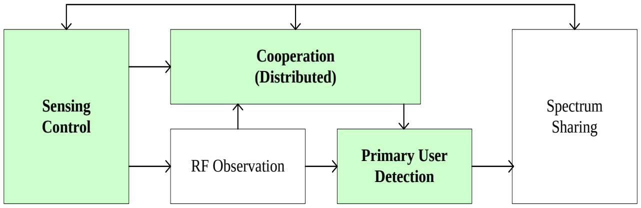

Fig. 4: Spectrum sensing structure for CRAHNs

3.1. Primary user detection

Since CR users are generally assumed not to have any real-time interaction with the PU transmitters and receivers, they do not know the exact information of the ongoing transmissions within the primary networks. Thus, PU detection depends on the only local radio observations of CR users. Generally, PU detection techniques for CRAHNs can be classified into three groups [4, 8]: *primary transmitter detection*, *primary receiver detection*, and *interference temperature management*.

Waleed et al. [5] have been presented a two-stage local spectrum sensing approach. In the first stage, each CR performs existing spectrum sensing techniques, i.e., energy detection, matched filter detection, and feature detection. In the second stage, the output from each technique is combined using fuzzy logic in order to deduce the presence or absence of a primary transmitter. Simulation results verify that the sensing approach technique outperforms existing local spectrum sensing techniques. The sensing approach shows significant improvement in sensing accuracy by exhibiting a higher probability of detection and low false alarms.

Thuc Kieu *et al*. [6], they have been presented a scheme for cooperative spectrum sensing on distributed cognitive radio networks. A fuzzy logic rule based inference system is used to estimate the presence possibility of the licensed user's signal based on the observed energy at each cognitive radio terminal.

3.2. Sensing Control

The main objective of spectrum sensing is to find more spectrum access opportunities without interfering with primary networks. To this end, the sensing operations of CR users are controlled and coordinated by a sensing controller, which considers two main issues on: (1) how long and frequently CR users should sense the spectrum to achieve sufficient sensing accuracy in in-band sensing, and (2) how quickly CR user can find the available spectrum band in out-of-band sensing, which are summarized in Fig. 6

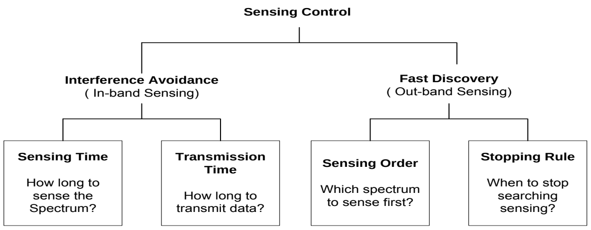

Fig. 6: Configuration parameters coordinated by sensing control

3.2.1. In-band sensing control

The first issue is related to the maximum spectrum opportunities as well as interference avoidance. The in-band sensing generally adopts the periodic sensing structure where CR users are allowed to access the spectrum only during the transmission period followed by sensing (observation) period. In the periodic sensing, longer sensing time leads to higher sensing accuracy, and hence to less interference. But as the sensing time becomes longer, the transmission time of CR users will be decreased. Conversely, while longer transmission time increases the access opportunities, it causes higher interference due to the lack of sensing information. Thus, how to select the proper sensing and transmission times is an important issue in spectrum sensing.

Sensing time optimization is investigated in [7] and [8], the sensing time is determined to maximize the channel efficiency while maintaining the required detection probability, which does not consider the influence of a false alarm probability. All efforts stated above, mainly focus on determining either optimal sensing time or optimal transmission time.

3.2.2. Out-of-band sensing control

When a CR user needs to find new available spectrum band (out-of-band sensing), a spectrum discovery time is another crucial factor to determine the performance of CRAHNs. Thus, this spectrum sensing should have a coordination scheme not only to discover as many spectrum opportunities as possible but also to minimize the delay in finding them. This is also an important issue in spectrum mobility to reduce the switching time. First, the proper selection of spectrum sensing order can help to reduce the spectrum discovery time in out-of-band sensing. In [9], an n-step serial search scheme is presented mainly focusing on correlated occupancy channel models, where the spectrum availability of current spectrum is assumed to be dependent on that of its adjacent spectrum

Copyright (c) 2014 International Journal of Computer Science Issues. All Rights Reserved.

bands. In [10] and [11], both transmission time and spectrum searching sequence are optimized by minimizing searching delay as well as maximizing spectrum opportunities.

3.3. Co-operative Sensing

In CRAHNs, each CR user needs to determine spectrum availability by itself depending only on its local observations. However the observation range of the CR user is small and typically less than its transmission range. Thus, even though CR users find the unused spectrum portion, their transmission may cause interference at the primary receivers inside their transmission range, the so-called receiver uncertainty problem [2]. Furthermore, if the CR user receives a weak signal with a low signal-to-noise ratio (SNR) due to multi-path fading, or it is located in a shadowing area, it cannot detect the signal of the PUs. Thus, in CRAHNs, spectrum sensing necessitates an efficient cooperation scheme in order to prevent interference to PUs outside the observation range of each CR user [2, 12].

A common cooperative scheme is forming clusters to share the sensing information locally. Such a scheme for wireless mesh networks is presented in [13], where the mesh router and the mesh clients supported by it form a cluster. Here, the mesh clients send their individual sensing results to the mesh router, which are then combined to get the final sensing result. Since CRAHNs do not have the central network entity, this cooperation should be implemented in a distributed manner.

For cooperation, when a CR user detects the PU activities, it should notify its observations promptly to its neighbors to evacuate the busy spectrum. To this end, a reliable control channel is needed for discovering neighbors of a CR user as well as exchanging sensing information.

Z.Quan *et al*. [14], an optimal cooperative sensing strategy is presented, where the final decision is based on a linear combination of the local test statistics from individual CR users. The combining weight for each user's signal indicates its contribution to the cooperative decision making. For example, if a CR user receives a higher-SNR signal and frequently makes its local decision consistent with the real hypothesis, then its test statistic has a larger weighting coefficient. In case of CR users in a deep fading channel, smaller weights are used to reduce their negative influence on the final decision. In the following subsection some of the key open research issues related to spectrum sensing will be introduced.

3.4. Open research issues in spectrum sensing

Optimizing the period of spectrum sensing, in spectrum sensing, the longer the observation period, the more accurate will be the spectrum sensing result. However, during sensing, a single-radio wireless transceiver cannot transmit in the same frequency band. Consequently, a longer observation period will result in lower system throughput. This performance tradeoff can be optimized to achieve an optimal spectrum sensing solution. Classical optimization techniques (e.g. convex optimization) can be applied to obtain the optimal solution.

Spectrum sensing in multichannel networks, in multichannel transmission (OFDM-based transmission) would be typical in a cognitive radio network. However, the number of available channels would be larger than the number of available interfaces at radio transceiver. Therefore, only a fraction of the available channels can be sensed simultaneously. Selection of the channels (among all available channels) to be sensed will affect the performance of the system. So, in multichannel environment, selection of the channels should be optimized for spectrum sensing to achieve optimal system performance.

4. Spectrum decision for cognitive radio networks

CRNs require capabilities to decide on the best spectrum band among the available bands according to the QoS requirements of the applications. This notion is called spectrum decision and it's closely related to the channel characteristics and the operations of PUs. Spectrum decision usually consists of two steps: First, each spectrum band is characterized based on not only local observations of CR users but also statistical information of primary networks. Then, based on this characterization, the most appropriate spectrum band can be chosen.

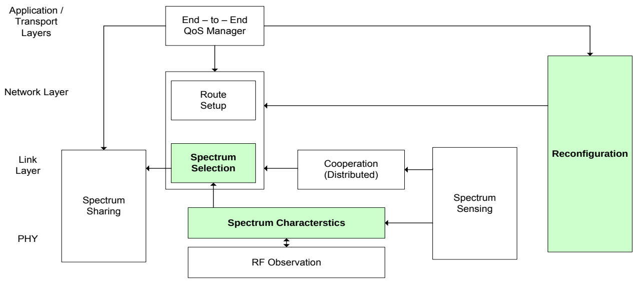

Fig. 7: Spectrum decision structure for CRAHNs

Generally, CRAHNs have unique characteristics in spectrum decision due to the nature of multi-hop communication. Spectrum decision needs to consider the end-to-end route consisting of multiple hops. Furthermore, available spectrum bands in CR networks differ from one hop to the other. As a result, the connectivity is spectrum dependent, which makes it challenging to determine the best combination of the routing path and spectrum. Thus, spectrum decision in ad hoc networks should interact with

Copyright (c) 2014 International Journal of Computer Science Issues. All Rights Reserved.

routing protocols. The following subsections are main functionalities required for spectrum decision as declared in Fig. 7.

4.1. Spectrum Characterization

In CRNs, multiple spectrum bands with different channel characteristics may be found to be available over a wide frequency range [15], it’s critical to first identify the characteristics of each available spectrum band. The following subsection, a spectrum characteristic in terms of radio environment and PU activity models will be discussed.

4.1.1. Radio Environment

Since the available spectrum holes show different characteristics, which vary over time, each spectrum hole should be characterized by considering both the time varying radio environment and the spectrum parameters such as operating frequency and bandwidth. Hence, it is essential to define parameters that can represent a particular spectrum band such as interference, path loss, wireless link errors, and link layer delay.

4.1.2. Primary user activity

In order to describe the dynamic nature of CR networks, we need a new metric to capture the statistical behavior of primary networks, called primary user (PU) activity. Since there is no guarantee that a spectrum band will be available during the entire communication of a CR user, the estimation of PU activity is a very crucial issue in spectrum decision.

Most of CR research assumes that PU activity is modeled by exponentially distributed inter-arrivals [16]. In this model, the PU traffic can be modeled as a two state birth–death process with death rate and birth rate b. An ON (Busy) state represents the period used by PUs and an OFF (Idle) state represents the unused period [17-19]. Since each user arrival is independent, each transition follows the Poisson arrival process. Thus, the length of ON and OFF periods are exponentially distributed.

There are some efforts to model the PU activity in specific spectrum bands based on field experiments. D.Willikomm *et al.* [20], the characteristics of primary usage in cellular networks are presented based on the call records collected by network systems, instead of real measurement. This analysis shows that an exponential call arrival model is adequate to capture the PU activity while the duration of wireless voice calls does not follow an exponential distribution. Furthermore, it is shown that a simpler random walk can be used to describe the PU activity under high traffic load conditions.

4.2. Spectrum selection

Once the available spectrum bands are characterized, the most appropriate spectrum band should be selected. Based on user QoS requirements and the spectrum characteristics, the data rate, acceptable error rate, delay bound, the transmission mode, and the bandwidth of the transmission can be determined. Then, according to a spectrum selection rule, the set of appropriate spectrum bands can be chosen.

In order to determine the best route and spectrum more efficiently, spectrum decision necessitates the dynamic decision framework to adapt to the QoS requirements of the user and channel conditions. Furthermore, in recent research, the route selection is performed independent of the spectrum decision. Although this method is quite simple, it cannot provide an optimal route because spectrum availability on each hop is not considered during route establishment. Thus, joint spectrum and routing decision method is essential for CRAHNs.

4.3. Reconfiguration

Besides spectrum and route selection, spectrum decision involves reconfiguration in CRAHNs. The protocols for different layers of the network stack must adapt to the channel parameters of the operating frequency. In [21], the adaptive protocols are presented to determine the transmission power as well as the best combination of modulation and error correction code for a new spectrum band by considering changes in the propagation loss. In the following subsection some of the key open research issues related to spectrum decision will be introduced.

4.4. Open research issues in spectrum decision

Data dissemination in cognitive radio ad-hoc networks, guaranteeing reliability of data dissemination in wireless networks is a challenging task. Indeed, the characteristics and problems intrinsic to the wireless links add several issues in the shape of message losses, collisions, and broadcast storm problem, just to name a few. Channel selection strategy is required to solve this problem.

Channel selection strategies are greatly influenced by the primary radio nodes activity. Study the impact of primary radio nodes activity on channel selection strategies is required. Also a decision model is required for spectrum access, stochastic optimization methods (e.g. the markov decision process) will be an attractive tool to model and solve the spectrum access decision problem in CRNs.

5. Spectrum sharing for cognitive radio networks

Copyright (c) 2014 International Journal of Computer Science Issues. All Rights Reserved.

The shared nature of the wireless channel necessitates coordination of transmission attempts between CR users. In this respect, spectrum sharing provides the capability to maintain the QoS of CR users without causing interference to the PUs by coordinating the multiple accesses of CR users as well as allocating communication resources adaptively to the changes of radio environment. Thus, spectrum sharing is performed in the middle of a communication session and within the spectrum band, and includes much functionality of a medium access control (MAC) protocol and resource allocation in classical ad hoc networks. Fig. 8 depicts the functional blocks for spectrum sharing in CRAHNs. In the following subsections, more details about functionalities for spectrum sharing will be explained.

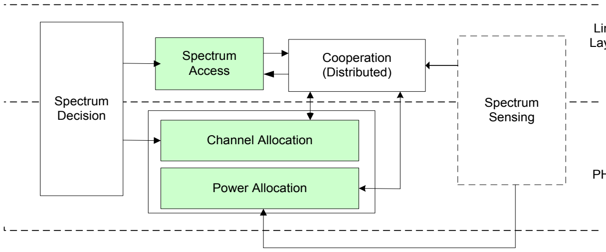

Fig. 8: Spectrum sharing structure for CRNs

5.1. Resource allocation

Based on the QoS monitoring results, CR users select the proper channels (channel allocation) and adjust their transmission power (power control) so as to achieve QoS requirements as well as resource fairness. Especially, in power control, sensing results need to be considered so as not to violate the interference constraints. In general, game theoretic approaches have been exploited to determine the communication resources of each user in CRAHNs [22, 23].

R.Etkin *et al.* [24], spectrum sharing for unlicensed band is presented based on the one-shot normal form game and repeated game. Furthermore, it is shown that orthogonal power allocation, i.e., assigning the channel to only one transmission to avoid co-channel interference with other neighbors, is optimal for maximizing the entire network capacity.

J.Huang *et al.* [25], both single channel and multi-channel asynchronous distributed pricing (SC/MC-ADP) schemes are presented, where each CR user announces its interference price to other nodes. Using this information from its neighbors, the CR user can first allocate a channel and in case there exist users in that channel, then, determine its transmitting power. While there exist users using distinct channels, multiple users can share the same channel by adjusting their transmit power. Furthermore, the SC-ADP algorithm provides higher rates to users when compared to selfish algorithms where users select the best channel without any knowledge about their neighbors' interference levels. While this method considers the channel and power allocation at the same time, it does not address the heterogeneous spectrum availability over time and space which is a unique characteristic in CRAHNs.

5.2. Spectrum access

It enables multiple CR users to share the spectrum resource by determining who will access the channel or when a user may access the channel. This is (most probably) a random access method due to the difficulty in synchronization. Spectrum sharing includes MAC functionality as well. However, unlike classical MAC protocols in ad hoc networks, CR MAC protocols are closely coupled with spectrum sensing, especially in sensing control described in Section 3.2.

Q.Zhang et al. [26], MAC layer packet transmission in the hardware constrained MAC (HC-MAC) protocol is presented. Typically, the radio can only sense a finite portion of the spectrum at a given time, and for single transceiver devices, sensing results in decreasing the data transmission rate. HC-MAC derives the optimal duration for sensing based on the reward obtained for correct results, as against the need aggressively scanning the spectrum at the cost of transmission time. A key difference of this protocol as against the previous work is that the sensing at either ends of the link is initiated after the channel contention on the dedicated CCC. The feasible channels at the two CR users on the link are then determined. However, the control messages used for channel negotiation may not be received by the neighboring nodes, and their transmission may influence the sensing results of the CR users that win the contention.

The presence of interferers that may cause jamming in the CR user frequencies are considered in the single-radio adaptive channel (SRAC) MAC protocol [27]. However, this work does not completely address the means to detect the presence of a jammer, and how the ongoing data transmission is switched immediately to one of the possible backup channels when the user is suddenly interrupted. In the following subsection, some of the key open research issues related to spectrum sharing will be introduced.

5.3. Open research Issues in spectrum sharing

Spectrum sharing necessitates sophisticated power control methods for adapting to the time-varying radio environment so as to maximize capacity with the protection of the transmission of Pus. The use of non-uniform channels by different CR users make topology discovery difficult, this required new mechanism to solve this problem.

6. Spectrum Mobility for CRNs

CR users are generally regarded as 'visitors' to the spectrum. Hence, if the specific portion of the spectrum in use is required by a PU, the communication needs to be continued in another vacant portion of the spectrum. This notion is called spectrum mobility. Spectrum mobility gives rise to a new type of handoff in CR networks, the so-called spectrum handoff, in which, the users transfer their connections to an unused spectrum band. In CRAHNs, spectrum handoff occurs: (1) when PU is detected, (2) the CR user loses its connection due to the mobility of users involved in an on-going communication, or (3) with a current spectrum band cannot provide the QoS requirements. Fig. 10 illustrates the functional blocks for spectrum mobility in CRAHNs.

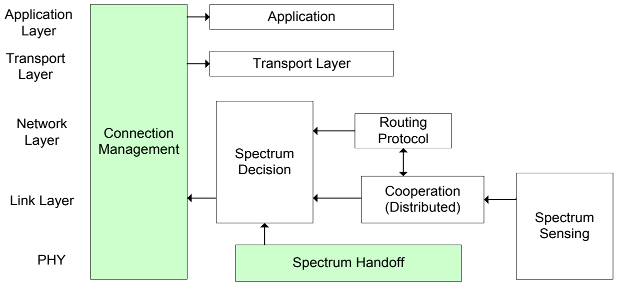

Fig. 10: Spectrum mobility structure for CRAHNs

The purpose of the spectrum mobility management in CRAHNs is to ensure smooth and fast transition leading to minimum performance degradation during a spectrum handoff. Furthermore, in spectrum mobility, the protocols for different layers of the network stack should be transparent to the spectrum handoff and the associated latency, and adapt to the channel parameters of the operating frequency. In the following subsection, the main functionalities required for spectrum mobility in the CRAHN are described.

6.1. Open research Issues in spectrum mobility

Switching delay mechanism is required to achieve faster switching time. Also, Flexible spectrum handoff framework is needed.

7. Proposed tools in spectrum management

Summary of the existing tools and simulator can be used to implement open research areas presented in Table 1. Open research areas which fall under spectrum sensing category are improved sensing accuracy and decreasing the interference with primary user. These issues implemented in Matlab using fuzzy logic or convex optimization tools.

Category	Proposed Tool	Suitable Simulator	Open research
Spectrum Sensing	Fuzzy logic [29] Optimization technique [30]	MATLAB	Improve sensing accuracy Decrease the interference with PU
Spectrum decision	Stochastic optimization [30] Markov process [28]	NS2/NS3 OMNET++	Channel selection strategy Data dissemination reliability
Spectrum sharing	Game theory [23]	NS2 GloMoSim	Sharing communication resources (frequency, transmission power) between CR users
Spectrum Mobility	Routing algorithm [31]	NS2/NS3	Handle spectrum handoff

In another category, Open research areas which fall under spectrum decision are channel selection strategy and data dissemination problems can be implemented in NS2 simulator or OMNET++ using stochastic optimization and markov process techniques [28]. Open research areas which fall under spectrum sharing are how to share communication resources (frequency, transmission power) between CR users, can be implemented in GloMoSim using game theory tool. Finally, in spectrum mobility, open research issues can be implemented in NS2 using routing algorithm technique.

8. Evolving future generation wireless networks in Egypt

Wireless communications systems are built based on the transmission of electromagnetic waves (i.e. radio waves) with frequencies in the range 3 Hz–300 GHz. The license frequencies of radio waves in Egypt divided into different groups/bands. Traditional spectrum management techniques which applied in Egypt, as defined by the Federal Communications Commission (FCC), are based on the command-and-control model. In this model, radio frequency bands are licensed to the authorized users by the government. The government (i.e. the auctioneer) determines the winning user/company, which is generally the user/company offering the highest bid. The licensed user is authorized to use the radio frequency band under certain rules and regulations (e.g. etiquette for spectrum usage) specified by the government. While most of the spectrum is managed under this command-and-control scheme, there are some spectrum bands that are reserved for industrial, scientific, and medical purposes, referred to collectively as the industrial, scientific, and medical (ISM) radio band. This ISM band can also be used for data communication. However, since there is no control on this

ISM band, the data communication could be interfered with by any ISM equipment.

The limitations in spectrum access due to the static spectrum licensing scheme can be summarized as follows:

- Fixed type of spectrum usage: In the current spectrum licensing scheme, the type of spectrum use cannot be changed. For example, a TV band in Egypt cannot be used by digital TV broadcast or broadband wireless access technologies. However, this TV band could remain largely unused due to cable TV systems.
- Licensed for a large region: When a spectrum is licensed, it is usually allocated to a particular user or wireless service provider in a large region (e.g. an entire city or state). However, the wireless service provider may use the spectrum only in areas with a good number of subscribers, to gain the highest return on investment. Consequently, the allocated frequency spectrum remains unused in other areas, and other users or service providers are prohibited from accessing this spectrum.
- Large chunk of licensed spectrum: A wireless service provider is generally licensed with a large chunk of radio spectrum (e.g. 50 MHz). For a service provider, it may not be possible to obtain license for a small spectrum band to use in a certain area for a short period of time to meet a temporary peak traffic load. For example, a cdma2000 cellular service provider may require a spectrum with bandwidth of 1.25MHz or 3.75MHz to provide temporary wireless access service in a hotspot area.
- Prohibit spectrum access by unlicensed users: In the current spectrum licensing scheme, only a licensed user can access the corresponding radio spectrum and unlicensed users are prohibited from accessing the spectrum even though it is unoccupied by the licensed users. For example, in a cellular system, there could be areas in a cell without any users. In such a case, unlicensed users with short-range wireless communications would not be able to access the spectrum, even though their transmission would not interfere with cellular users.

In order to improve the efficiency and utilization of the available spectrum in Egypt, these limitations are being remedied by modifying the spectrum licensing scheme. The idea is to make spectrum access more flexible by allowing unlicensed users to access the radio spectrum under certain restrictions using CR technology. The objectives behind these recommendations were to improve both the technical and economic efficiency of spectrum management. From a technical perspective, spectrum management needs to ensure the lowest interference and the highest utilization of the radio frequency band. The economic aspects of spectrum management relate to the revenue and satisfaction of the spectrum licensee.

The evolving future generation wireless networks in Egypt will have the following attributes:

High transmission rate: New wireless applications and services, e.g. video and file transfer, require higher data rate to reduce the data transmission time and support a number of users. Many advanced techniques in the physical layer have been developed to increase the data rate without increasing spectrum bandwidth and transmit power requirement.

QoS support: Various types of traffic, e.g. voice, video, and data, will be supported by the next generation wireless system. Service differentiation and QoS support are required to prioritize different types of traffic according to the performance requirement. Radio resource management framework has to be designed to efficiently access the available spectrum.

Integration of different wireless access technologies: Next generation wireless networks will use the IP technology to glue the different wireless access technologies to a converged wireless system. In this converged network, multi-interface mobile units will be common. With multiple radio interfaces, a mobile should be able to connect to different wireless networks using different access technologies simultaneously. For example, a mobile can connect to a WLAN through the IEEE 802.11 based radio interface. However, when this mobile moves out of range of the WLAN, it can connect to a cellular network (e.g. using a 3G air interface) or a WiMAX network to resume the communication session. Such a heterogeneous wireless access network provides two major advantages: it enhances the data transmission rate since multiple data streams can be transmitted concurrently, and it enables seamless mobility through providing wireless connectivity anytime and anywhere.

Integration of cognitive radio concepts in traditional wireless systems: Cognitive radio and dynamic spectrum access techniques can be integrated into traditional wireless communications systems to achieve better flexibility of radio resource usage so that the system performance can be improved. For example, load balancing/dynamic channel selection in traditional cellular wireless systems and WLANs, distributed subcarrier allocation in OFDM systems, and transmit power control in UWB systems can be achieved by using dynamic spectrum access-based cognitive radio techniques.

Emergence of cognitive radio-based wireless applications and services: Emerging wireless services and applications, a few of which are described, can take advantage of cognitive radio:

Future generation wireless Internet services: Next generation wireless Internet is expected to provide seamless QoS guarantee to mobile users for a variety of multimedia applications. Cognitive radio technology based on dynamic spectrum access will facilitate provisioning of these future generation wireless Internet services.

Wireless ehealth services: In a remote patient monitoring system, biosignal sensors attached to patients can transmit monitored data (e.g. heart rate and blood pressure) to the healthcare center for diagnostic and monitoring purposes. WLAN and WPAN technology can be used for wireless patient monitoring applications when patients are either in the hospital or at home. Since the constraints on electromagnetic interference (EMI) could be very stringent in such environments, cognitive radio technology based on dynamic spectrum access would be promising for providing wireless communications services.

Public safety services: Communications services for public safety can take advantage of the cognitive radio technology based on dynamic spectrum access to achieve the desired service objectives (e.g. prioritizing emergency calls over other commercial service calls).

9. Conclusion

Cognitive radio technology has been proposed in recent years as a revolutionary solution towards more efficient utilization of the scarce spectrum resources in an adaptive and intelligent way. By tuning the frequency to the temporarily unused licensed band and adapting operating parameters to environment variations, cognitive radio technology provides future wireless devices with additional bandwidth, reliable broadband communications, and versatility for rapidly growing data applications. To realize the goal of spectrum aware communication, the CR devices need to incorporate the spectrum sensing, decision, sharing, and mobility functionalities. The main challenge in CRAHNS is to integrate these functions in the layers of the protocol stack, so that the CR users can communicate reliably in a distributed manner over multi-hop/multi-spectrum environment without infrastructure support. The discussions provided in this paper strongly supporter cooperative spectrum aware communication protocols that consider the spectrum management functionalities. The proposed tool and simulator in this paper gives insight in choosing the best suitable tool that fits for different categories of spectrum management.

References

[1] Tarek M.Salem, Sherine M. Abd El-kader, Salah M.Ramadan, M.Zaki, “Efficient spectrum management: challenges and solutions”, book chapter submitted to: CRC Press - Taylor & Francis Group, USA, 2014.

[2] S. Haykin, “Cognitive radio: brain-empowered wireless communications”, *IEEE Journal on Selected Areas in Communication,s*, vol. 23, no. 2, pp.201-220, 2010.

[3] M. A. McHency, P. A. Tenhula, D. McCloskey, D. A. Reberson, and C. S. Hood, “Chicago spectrum occupancy measurements and analysis and a long- term studies proposal protocol,” in *Proc. 1st Int. Workshop on Technology and Policy for Accessing Spectrum*, Boston, MA, USA, Aug. 2009.

[4] M. Nekovee, “A survey of cognitive radio access on TV white spaces,” *Hindawi International Journal of Digital Multimedia Broadcasting, Article ID: 236568*, pp. 1–11, 2010.

[5] Waleed Ejaz, and others, “Improved local spectrum sensing for cognitive radio networks”, *EURASIP Journal on Advances in Signal Processing*, vol. 2, no. 1, 2012.

[6] A. Ghasemi, E.S. Sousa, “*Spectrum sensing in cognitive radio networks: requirements. Challenges and Design Trade-offs*. IEEE Commun. Mag, vol.46, no.4, pp.32–39, 2011.

[7] A. Ghasemi, E.S. Sousa, “Optimization of spectrum sensing for opportunistic spectrum access in cognitive radio networks”, *Proceedings of the IEEE Consumer Communications and Networking Conference (CCNC)*, pp. 1022–1026, Las Vegas, NV, USA, Jan, 2011.

[8] P. Wang, L. Xiao, S. Zhou, J. Wang, “Optimization of detection time for channel efficiency in cognitive radio systems”, *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 111–115, Hong Kong, China, March 2010.

[9] L. Luo, S. Roy, “Analysis of search schemes in cognitive radio”, *Proceedings of the IEEE SECON*, pp. 647–654.San Diego, CA, USA, June 2010.

[10] H. Kim, K.G. Shin, “Efficient discovery of spectrum opportunities with MAC-layer sensing in cognitive radio networks”, *IEEE Transactions on Mobile Computing*, vol.7, no.5, pp. 533-545, 2010.

[11] H. Kim, K.G. Shin, “Fast discovery of spectrum opportunities in cognitive radio networks”, *Proceedings of the IEEE DySPAN*, Chicago, IL, USA, October 2010.

[12] C. Cordeiro, K. Challapali, “C-MAC: a cognitive MAC protocol for multi-channel wireless networks”, *Proceedings of the IEEE DySPAN*, pp. 147–157, April 2011.

[13] F. Digham, M. Alouini, M. Simon, “On the energy detection of unknown signals over fading channels”, *Proceedings of the IEEE ICC*, vol. 5, pp. 3575–3579, May 2010.

[14] Z. Quan, S. Cui, A.H. Sayed, “Optimal linear cooperation for spectrum sensing in cognitive radio networks”, *IEEE Journal of Selected in Signal Processing*, vol. 2, no. 1, pp. 28–40, 2012.

[15] M. Gandetto, C. Regazzoni, “Spectrum sensing: a distributed approach for cognitive terminals”, *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 3, pp. 546-557, 2010.

Copyright (c) 2014 International Journal of Computer Science Issues. All Rights Reserved.

[16] C. Chou, S. Shankar, H. Kim, K.G. Shin, “What and how much to gain by spectrum agility?”, *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 3, pp. 576–588, 2010.
[17] G. Yuan, R. Grammenos, Y. Yang, and W. Wang, “Performance analysis of selective opportunistic spectrum access with traffic prediction,” *Vehicular Technology, IEEE Transactions on*, vol. 59, no. 4, pp. 1949 –1959, may 2011.
[18] A. W. Min and K. G. Shin, “Exploiting multi-channel diversity in spectrum-agile networks,” *Proceedings of INFOCOM*, pp. 1921 – 1929, 13-18 April 2008.
[19] W.-Y. Lee and I. Akyildiz, “Optimal spectrum sensing framework for cognitive radio networks,” Wireless Communications, IEEE Transactions on, vol. 7, no. 10, pp. 3845 –3857, october 2012.
[20] D. Willkomm, S. Machiraju, J. Bolot, A. Wolisz, “Primary users in cellular networks: a large-scale measurement study”, *Proceedings of the IEEE DySPAN* 2010, Chicago, IL, USA, October 2010.
[21] M.B. Pursley, T.C. Royster IV, “Low-complexity adaptive transmission for cognitive radios in dynamic spectrum access networks”, *IEEE Journal on Selected Areas in Communications,* vol. 26, no. 1, pp. 83–94, 2010.
[22] R. Etkin, A. Parekh, D. Tse, “Spectrum sharing for unlicensed bands”, *IEEE Journal of Selected Areas in Communications,* vol. 25, no. 3, pp. 517–528, 2010.
[23] Z. Ji, K.J.R. Liu, “Dynamic spectrum sharing: a dynamic spectrum sharing: a game theoritical overview”, *IEEE Communications Magazine,* vol. 4, no. 5, pp. 88–94, 2009.
[24] J. Huang, R.A. Berry, M.L. Honig, “Spectrum sharing with distributed interference compensation”, *Proceedings of the IEEE DySPAN* 2008, pp. 88–93, November 2005.
[25] J. Jia, Q. Zhang, X. Shen, “HC-MAC: a hardware-constrained cognitive MAC for efficient spectrum management”, *IEEE Journal on Selected Areas in Communications*, vol.26, no.1, pp. 106-117, 2010.
[26] F.K. Jondral, “Software-defined radio: basic and evolution to cognitive radio”, *EURASIP Journal on Wireless Communication and Networking*, vol. 2, no. 1, 2011.
[27] E. Jung, X. Liu, “Opportunistic spectrum access in heterogeneous user environments”, *Proceedings of the IEEE DySPAN*, Chicago, IL, USA, October. 2010.
[28] L. Ma, C.-C. Shen, B. Ryu, “Single-radio adaptive channel algorithm for spectrum agile wireless ad hoc networks”, *Proceedings of the IEEE DySPAN*, pp. 547–558, April 2009.
[29] Yi Shi, and others, “Distributed Cross-Layer Optimization for Cognitive Radio Networks”, *IEEE Journal on Selected Areas in Communications*, vol. 2, no. 1, 2012.
[30] Alrabaee, S.; Khasawneh, M.; Agarwal, A.; Goel, N.; Zaman, M. "A game theory approach: Dynamic behaviours for spectrum management in cognitive radio network", IEEE *Globecom Workshops (GC Wkshps),* pp. 919 – 924, 2013.
[31] Matteo Cesana, and others, “Routing in cognitive radio networks: Challenges and solutions”, *Computer Communications Elsevier Journal*, 2013.

AUTHOR

Tarek M. Salem is an assistant researcher in Computers and Systems Department at the Electronics Research Institute (ERI) in Egypt. In May 2005, he completed her B.S. in Computers and Systems department, Faculty of Engineering, Al-Azhar University. During the 2005-2012 year, he joined the Arabic Organization for Industrialization. In 2013 year, he occupied the position of research assistant at Electronics Research Institute. Now, he is studying for Ph.D. degree.

S. Abd El-kader has her MSc, & PhD degrees from the Electronics & Communications Dept. & Computers Dept., Faculty of Engineering, Cairo University, at 1998, & 2003. Dr. Abd El-kader is an Associate Prof., Computers & Systems Dept., at the Electronics Research Institute (ERI). She is currently supervising 3 PhD students, and 10 MSc students. Dr. Abd El-kader has published more than 25 papers, 4 book chapters in computer networking area. She is an Associate Prof., at Faculty of Engineering, Akhbar El Yom Academy from 2007 till 2009. Also she is a technical reviewer for many international Journals. She is heading the Internet and Networking unit at ERI from 2003 till now. She is also heading the Information and Decision making support Center at ERI from 2009 till now.

Salah M.Ramadan has his MSc, & PhD degrees from the Systems & Computers Dept. Faculty of Engineering, Al-Azhar University, Dr. Salah M.Ramadan has published more than 15 papers, in computer networking area. He is an Associate Prof., at Faculty of Engineering, Al-Azhar University.

M.Zaki has his MSc, & PhD degrees from the Systems & Communications Dept. Faculty of Engineering, Al-Azhar University, Dr. **M.Zaki** has published more than 75 papers, in computer networking area. He is a Prof., at Faculty of Engineering, Al-Azhar University.