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A Study on Spectrum Sharing Approach Using Cognitive Radio To Enhance Throughput Efficiency of Ad Hoc Networks

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ABSTRACT

Cognitive radios hold tremendous promise for increasing spectral efficiency in wireless systems. The spectrum sensing problem has gained new aspects with cognitive radio and opportunistic spectrum access concepts. It is one of the most challenging issues in cognitive radio systems. A cognitive radio is an intelligent wireless communication device that exploits side information about its environment to improve spectrum utilization. Spectrum shortage was born the idea for cognitive radios. These devices utilize advanced radio and signal processing technology along with novel spectrum allocation policies to support new wireless users operating in the existing crowded spectrum, without degrading the performance of entrenched users. In this paper we present a Cognitive Radio approach for usage of Virtual Unlicensed Spectrum , a vision of a Cognitive Radio (CR) based approach that uses allocated spectrum in a opportunistic manner to create "virtual unlicensed bands" i.e. bands that are shared with the primary (often licensed) users on a non-interfering basis. Dynamic spectrum management techniques are used to adapt immediate local spectrum availability. One of the most important components of the cognitive radio concept is the ability to measure, sense, learn, and be aware of the parameters related to the radio channel characteristics, availability of spectrum and power, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions. In cognitive radio terminology, *primary users* can be defined as the users who have higher priority or legacy rights on the usage of a specific part of the spectrum.

Introduction

The radio spectrum is a scarce resource. It is commonly believed that there is a crisis of spectrum availability at frequencies that can be economically used for wireless communications. New developments in broadcast and mobile communication technologies have increased the demand for radio-frequency spectrum, a finite natural resource. Cognitive radio is a new technology that allows spectrum to be dynamically shared between users. More precisely: "A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which it operates [1].

Cognitive radio refers to an intelligent radio, which has the ability to sense the external environment, learn from history and make intelligent decisions to adjust its transmission parameters according to the current state of the wireless channel. Spectrum sensing is an important aspect in the implementation of cognitive radios. The efficiency of spectrum sensing is largely impacted by the interferences in the primary channel. It offers the potential to dramatically change the way spectrum is used in systems and to substantially increase the amount of spectrum available for wireless. Recent technological advances have resulted in the development of wireless ad hoc networks composed of devices that are self-organizing and can be deployed without infrastructure support is illustrated in Fig 1. These devices generally have small form factors, and have embedded storage, processing and communication ability. While ad hoc networks may support different wireless standards, the current state-of- the art has been mostly limited to their operations in the 900 MHz and the 2.4 GHz Industrial, Scientific and Medical (ISM) bands. With the growing proliferation of wireless devices, these bands are increasingly getting congested. At the same time, there is several frequency bands licensed to operators, such as in the 400–700 MHz range, that are used sporadically or under-utilized for transmission.

The licensing of the wireless spectrum is currently undertaken on a long-term basis over vast geographical regions. In order to address the critical problem of spectrum scarcity, the FCC has recently approved the use of unlicensed devices in licensed bands. Consequently, dynamic spectrum access (DSA) techniques are proposed to solve these current spectrum inefficiency problems. This new area of research foresees the development of cognitive radio (CR) networks to further improve spectrum efficiency [5][6][7]. The basic idea of CR networks is that the unlicensed devices (also called cognitive radio users or secondary users) need to vacate the band once the licensed device (also known as a primary user) is detected. CR networks, however, impose unique challenges due to the high fluctuation in the available spectrum as well as diverse quality of-service (QoS) requirements.

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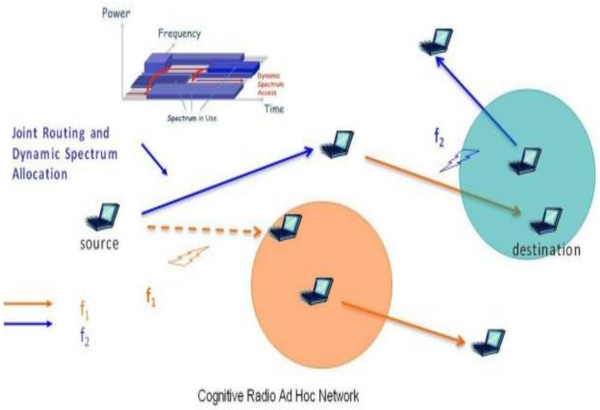

Fig. 1. Cognitive Radio Ad Hoc Network

The availability of spectrum holes, i.e., frequency bands assigned to a primary user but that are vacant in a given place at a given time, can be estimated with spectrum sensing techniques, such as energy detection and feature detection is given in Fig.2. When little or no knowledge of the primary user signal is available, energy detection is useful while feature detection can exploit a priori information about the used waveforms. We have studied the performance of an energy detection scheme in terms of probability of detection and probability of false alarm without and with cooperation between the nodes. Cooperative detection by combining the observations of several cognitive radio nodes can be used to improve the performance of spectrum sensing.

In addition to the estimation of the availability of spectrum holes, the predicted length of the spectrum holes is of interest in selecting suitable communication channels.

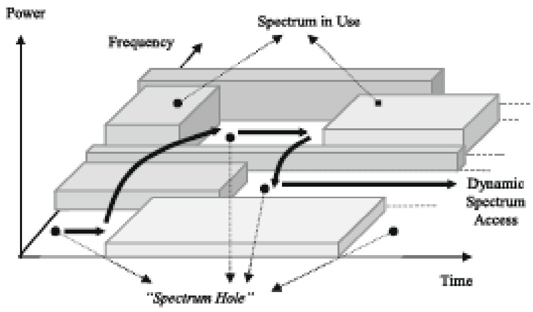

Fig. 2. Spectrum Holes

Spectrum Management Framework For Cognitive Radio Ad Hoc Networks

The components of the cognitive radio ad hoc network (CRAHN) architecture 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)1 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.

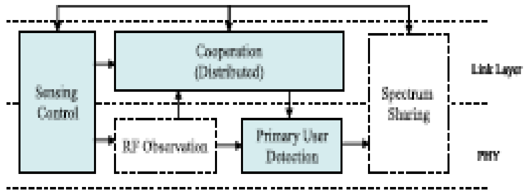

Fig. 3. Spectrum Sensing Structure for Ad hoc CR Networks

In order to adapt to dynamic spectrum environment, the CRAHN necessitates the spectrum-aware operations, which form a cognitive cycle as shown in Fig. 3, the steps of the cognitive cycle consist of four spectrum management functions: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility. To implement CRAHNs, each function needs to be incorporated into the classical layering protocols, as shown in Fig. 4. The following section discusses about main features of spectrum management functions [3].

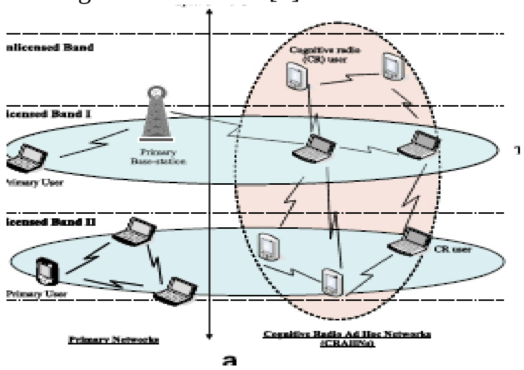

Fig. 4. Ad Hoc network sharing primary networks

Spectrum Management

A CR user can be allocated to only an unused portion of the spectrum. Therefore, a CR user should monitor the available spectrum bands, and then detect spectrum holes.

A. Spectrum sensing

It is a basic functionality in CR networks, and hence it is closely related to other spectrum management functions as well as layering protocols to provide information on spectrum availability

B. Spectrum decision

Once the available spectrums are identified, it is essential that the CR users select the most appropriate band according to their QoS requirements. It is important to characterize the spectrum band in terms of both radio environment and the statistical behaviors of the PUs. In order to design a decision algorithm that incorporates dynamic spectrum characteristics, we need to obtain a priori information regarding the PU activity.

Furthermore, in CRAHNs, spectrum decision involves jointly undertaking spectrum selection and route formation.

C. Spectrum sharing

Since there may be multiple CR users trying to access the spectrum, their transmissions should be coordinated to prevent collisions in overlapping portions of the spectrum. Spectrum sharing provides the capability to share the spectrum resource opportunistically with multiple CR users which includes resource allocation to avoid interference caused to the primary network. For this, game theoretical approaches have also been used to analyze the behavior of selfish CR users. Furthermore, this function necessitates a CR medium access control (MAC) protocol, which facilitates the sensing control to distribute the sensing task among the coordinating nodes as well as spectrum access to determine the timing for transmission.

D. Spectrum mobility

If a PU is detected in the specific portion of the spectrum in use, CR users should vacate the spectrum immediately and continue their communications in another vacant portion of the spectrum. For this, either a new spectrum must be chosen or the affected links may be circumvented entirely. Thus, spectrum mobility necessitates a spectrum handoff scheme to detect the link failure and to switch the current transmission to a new route or a new spectrum band with minimum quality degradation. This requires collaborating with spectrum sensing, neighbor discovery in a link layer, and routing protocols. Furthermore, this functionality needs a connection management scheme to sustain the performance of upper layer protocols by mitigating the influence of spectrum switching.

E. The spectrum occupancy

Completely free, partially free and fully occupied, is known as *white*, *grey* and *black* holes in spectrum usage.

Spectrum Sensing For Cognitive Radio Ad Hoc 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 is depicted in Fig.4. 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 networks so as to avoid interference (in band sensing).

Spectrum Sensing Methods For Cognitive Radio

The present literature for spectrum sensing is still in its early stages of development. A number of different methods are proposed for identifying the presence of signal transmissions. In some approaches, characteristics of the identified transmission are detected for deciding the signal transmission as well as identifying the signal type. In this section, some of the most common spectrum sensing techniques in the cognitive radio literature are explained.

Spectrum Sensing In Current Wireless Standards

Recently developed wireless standards have started to include cognitive features. Even though it is difficult to expect a wireless standard that is based on wideband spectrum sensing and opportunistic exploitation of the spectrum, the trend is in this direction. In this section, wireless technologies that require some sort of spectrum sensing for adaptation or for dynamic frequency access (DFA) are discussed. However, the spectrum knowledge can be used to initiate advanced receiver algorithms as well as adaptive interference cancellation [18].

Sensing Duration and Frequency

Primary users can claim their frequency bands anytime while cognitive radio is operating on their bands. In order to prevent interference to and from primary license owners, cognitive radio should be able to identify the presence of primary users as quickly as possible and should vacate the band immediately. Hence, sensing methods should be able to identify the presence of primary users within certain duration. This requirement poses a limit on the performance of sensing algorithm and creates a challenge for cognitive radio design.

Selection of sensing parameters brings about a tradeoff between the speed (sensing time) and reliability of sensing. Sensing frequency, *i.e.* how often cognitive radio should perform spectrum sensing, is a design parameter that needs to be chosen carefully. The optimum value depends on the capabilities of cognitive radio itself and the temporal characteristics of primary users in the environment [13]. If the statuses of primary users are known to change slowly, sensing frequency requirements can be relaxed. A good example for such a scenario is the detection of TV channels. The presence of a TV station usually does not change frequently in a geographical area unless a new station starts broadcasting or an existing station goes offline. In the IEEE 802.22 draft standard, for example, the sensing period is selected as 30 seconds. In addition to sensing frequency, the channel detection time, channel move time and some other timing related parameters are also defined in the standard [18]. Another factor that affects the sensing frequency is the interference tolerance of primary license owners. For example, when a cognitive radio is exploiting opportunities in public safety bands, sensing should be done as frequently as possible in order to prevent any interference.

Furthermore, cognitive radio should immediately vacate the band if it is needed by public safety units. The effect of sensing time on the performance of secondary users is investigated in [19]. Optimum sensing durations to search for an available channel and to monitor a used channel are obtained. The goal is to maximize the average throughput of secondary users while protecting primary users from interference.

IEEE 802.11k Standard

A proposed extension to IEEE 802.11 specification is IEEE 802.11k which defines several types of measurements [19]. Some of the measurements include channel load report, noise histogram report and station statistic report. The noise histogram report provides methods to measure interference levels that display all non-802.11 energy on a channel as received by the subscriber unit. AP collects channel information from each mobile unit and makes its own measurements. This data is then used by the AP to regulate access to a given channel. The sensing (or measurement) information is used to improve the traffic distribution within a network as well. WLAN devices usually connect to the AP that has the strongest signal level. Sometimes, such an arrangement might not be optimum and can cause overloading on one AP and underutilization of others. In 802.11k, when an AP with the strongest signal power is loaded to its full capacity, new subscriber units are assigned to one of the underutilized APs. Despite the fact that the received signal level is weaker, the overall system throughput is better thanks to more efficient utilization of network resources.

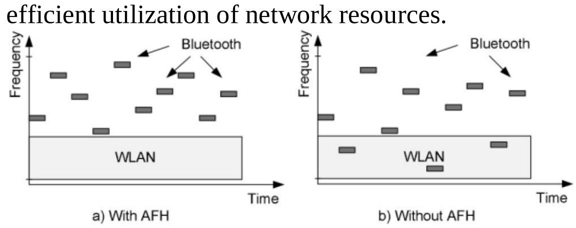

Fig. 5. Adaptive frequency hopping

Bluetooth Network

In Fig.5 a new feature, namely adaptive frequency hopping (AFH), is introduced to the Bluetooth standard to reduce interference between wireless technologies sharing the 2.4GHz unlicensed radio spectrum [12], [13]. In this band, IEEE 802.11b/g devices, cordless telephones, and microwave ovens use the same wireless frequencies as Bluetooth. AFH identifies the transmissions in the industrial, scientific and medical (ISM) band and avoids their frequencies. Hence, narrow-band interference can be avoided and better bit error rate (BER) performance can be achieved as well as reducing the transmit power. Fig. 5 shows an illustrative Bluetooth transmission with and without AFH. By employing AFH, collisions with WLAN signals are avoided in this example. AFH requires a sensing algorithm for determining whether there are other devices present in the ISM band and whether or not to avoid them. The sensing algorithm is based on statistics gathered to determine which channels are occupied and which channels are empty. Channel statistics can be packet-error rate, BER, received signal strength indicator (RSSI), carrier to-interference-plus-noise ratio (CINR) or other metrics [12]. The statistics are used to classify channels as *good*, *bad*, or *unknown* [13].

IEEE 802.22 Standard

IEEE 802.22 standard is known as *cognitive radio standard* because of the cognitive features it contains. The standard is still in the development stage. One of the most distinctive features of the IEEE 802.22 standard is its spectrum sensing requirement [16]. IEEE 802.22 based wireless regional area network (WRAN) devices sense TV channels and identify transmission opportunities. The functional requirements of the standard require at least 90% probability of detection and at most 10% probability of false alarm for TV signals with - 116 dBm power level or above [17]. The sensing is envisioned to be based on two stages: fast and fine sensing [18]. In the fast sensing stage, a coarse sensing algorithm is employed, *e.g.* energy detector. The fine sensing stage is initiated based on the fast sensing results.

Fine sensing involves a more detailed sensing where more powerful methods are used. Several techniques that have been proposed and included in the draft standard include energy detection, waveform-based sensing (PN511 or PN63 sequence detection and/or segment sync detection), cyclostationary feature detection, and matched filtering. A base station (BS) can distribute the sensing load among subscriber stations (SSs).

PU detection: The CR user observes and analyzes its local radio environment. Based on these location observations of itself and its neighbors, CR users determine the presence of PU transmissions, and accordingly identify the current spectrum availability[18].

Cooperation: The observed information in each CR user is exchanged with its neighbors so as to improve sensing accuracy.

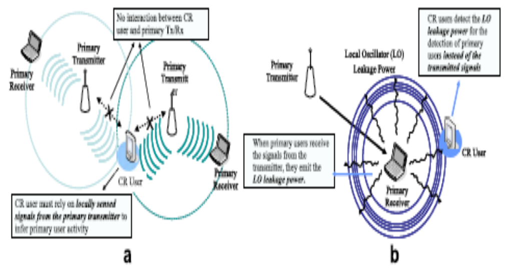

Fig. 6. (a)Spectrum Sensing Technique Transmitter detection, and (b) receiver detection

Spectrum mobility for cognitive radio ad hoc

Networks 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[19].

In spectrum handoff, temporary communication break is inevitable due to the process for discovering a new available spectrum band. Since available spectrums are dis-contiguous and distributed over a wide frequency range, CR users may require the reconfiguration of operation frequency in its RF front-end, which leads to significantly longer switching time. The purpose of the spectrum mobility- Spectrum sharing challenges in CRAHNs. mobility management in CRAHNs is to ensure smooth and fast.

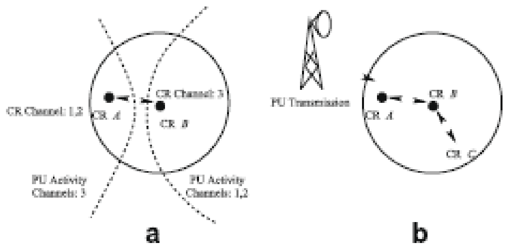

Fig. 7. Spectrum sharing challenges in CRAHNs.

Research Challenges

Determination of channel structure

Under the commons model, the spectrum is made available as a contiguous frequency block, that must be separated into channels for use by the CR users. The number of channels should be such that the CR users have sufficient choice is choosing distinct and non-overlapping channels whenever possible, and at the same time be able to sustain a minimum desired channel throughput. In the absence of a central entity, balancing this tradeoff by creating an optimal number of channel divisions is a challenge.

Detection of selfish behavior

As the spectrum is shared by the CR users, they may choose the channel structure independently of the others. Moreover, users belonging to different CR operators may have different channel specifications, such as the amount of allowed spectral leakage in the neighboring channels, transmission masks, channel bandwidth, among others. In such cases, it is important to detect the CR users that exhibit selfish behavior by using the spectrum that exceeds the regulations laid down by the specifications . This may allow some of the CR users to unfairly improve their performance at the cost of the others, making it necessary to devise strategies to detect this selfish behavior. Penalizing and regulatory policing: As CR ad hoc networks do not have a centralized admission control scheme, penalizing the CR users for selfish or malicious behavior is difficult. Moreover, regulatory policing rules must be established for each free spectrum pool, so that CR users can collectively decide on their inclination to forward traffic originating from the node engaging in selfish.

Conclusion

CR networks are envisaged to solve the problem of spectrum scarcity by making efficient and opportunistic use of frequencies reserved for the use of licensed users of the bands. To realize the goals of truly ubiquitous spectrum-aware communication, the CR devices need to incorporate the spectrum sensing, spectrum decision, spectrum sharing, and spectrum 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 a multi-hop/multi-spectrum environment, without any infrastructure support.

The discussions provided in this study strongly advocate cooperative spectrum-aware communication protocols that consider the spectrum management functionalities. Many researchers are currently engaged in developing the communication technologies and protocols required for CRAHNs. However, to ensure efficient spectrum-aware communication, more research is needed along the lines introduced in this paper.

References

[1] FCC, *Cognitive Radio Workshop*, May 19, 2010,[Online] Available:

[2] http://www.fcc.gov/searchtools.html.

[3] *Proc. Conf. Cogn. Radios*, Las Vegas, NV, Mar.15–16, 2009.

[4] K. Akkaya, M. Younis, A survey on routing Protocols for wireless sensor networks, Ad Hoc Networks (Elsevier) 3 (3) (2009) 325–349.

[5] http://www.fcc.gov/oet/info/database/spectrum/

[6] FCC. Et docket no. 02-155. Order, May 2002.

[7] FCC. Et docket no. 03-322. Notice of Proposed Rule Making and Order, December 2003.

[8] I.F. Akyildiz, W.-Y. Lee, M.C. Vuran, M. Shantidev, NeXt generation dynamic spectrum Access/cognitive radio wireless networks: a survey, Computer Networks Journal (Elsevier) 50 (2006) 2127–2159.

[9] A. Al Daoud, M. Alanyali, D. Starobinski, Secondary pricing of spectrum in cellular CDMA networks, in: Proceedings of the IEEE DySPAN 2007, Dublin, Ireland, April 2007, pp. 535–542.

[10] R.W. Brodersen, A. Wolisz, D. Cabric, S.M. Mishra, D. Willkomm, Corvus: a cognitive radio approach for usage of virtual unlicensed spectrum, Berkeley Wireless Research Center (BWRC) White paper, 2004.

[11] D. Cabric, S.M. Mishra, R.W. Brodersen, Implementation issues in spectrum sensing for cognitive radios, in: Proceeings of the IEEE Asilomar Conference on Signals, Systems and Computers 2004, November 2004, pp. 772–776.

[12] N. Golmie, N. Chevrollier, and O. Rebala, “Bluetooth and WLAN coexistence: challenges and solutions,” *IEEE Wireless Commun. Mag.* vol. 10, no. 6, pp. 22–29, Dec. 2009.

[13] *Specification of the Bluetooth system, Master Table of Contents &Compliance Requirements*, Bluetooth, SIG Std. Bluetooth Standard,Nov. 2010.

[14] D. Cabric, A. Tkachenko, R.W. Brodersen, Spectrum sensing measurements of pilot, energy, and collaborative detection, in: Proceedings of the IEEE Military Communications Conference (MILCOM), October 2006.

[15] Canberk, I.F. Akyildiz, S. Oktug, Primary user activity modeling using first-difference filter clustering and correlation in cognitive radio networks, December 2008, submitted for publication.

[16] L. Cao, H. Zheng, Distributed spectrum allocation via local bargaining, in: Proceedings of the IEEE Sensor and Ad Hoc Communications and Networks (SECON), September 2005, pp.475–486.

[17] L. Cao, H. Zheng, Distributed rule-regulated spectrum sharing, IEEE Journal on Selected Areas in Communications 26 (1) (2008) 130–145.

[18] Capone, L. Fratta, F. Martignon, Bandwidth estimation schemes for TCP over wireless networks, IEEE Transactions on Mobile Computing 3 (2) (2004) 129–143.

[19] T. Chen, H. Zhang, G.M. Maggio, I. Chlamtac, CogMesh: a clusterbased cognitive radio network, in: Proceedings of the IEEE DySPAN, April 2007, pp. 168–178.