

Simulation Model of Spectrum Handoff Process for Medium Access Control Protocols in Cognitive Radio Networks

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Abstract

Cognitive radio is a new technology that improves spectrum utilization by allowing secondary users to use licensed channels in an opportunistic manner. Because primary users have a right to use their licensed channels at any time, it is necessary for secondary users to stop their transmissions or to continue their transmissions in other channels in case of action of primary users. The event of changing channel for secondary users is known as spectrum handoff. Spectrum handoff for medium access protocols is an emerging topic because of the increasing spectrum scarcity. In this paper, simulation model of a cognitive radio network that consists of primary users and secondary users is considered. Riverbed Modeler Simulation Software is used for simulation scenarios. Secondary users are designed to make spectrum handoff between time slots of primary users with reactive decision spectrum handoff. It is clearly seen that number of handoff is significantly decreased by means of instant sensing based reactive spectrum handoff.

1. Introduction

Cognitive radio is an emerging technology that enhances spectrum usage by means of unique sensing mechanism [1, 2]. With the help of spectrum sensing mechanism, secondary users discover underutilized spectrum holes, and exploit these spectrum holes without obstructing licensed primary users [2, 3]. In case of appearance of primary users in licensed channels, secondary users cease their communications or find a new channel to carry on their communications [4, 5]. Continuing a transmission in a new channel of secondary users in order not to cause any interference to the primary users is called as spectrum handoff strategy. In spectrum handoff, secondary users alter their transmission channel with reactive decision or proactive decision [6]. In reactive decision spectrum handoff, secondary users find a new channel in an on-demand manner with spectrum sensing technology. In proactive decision spectrum handoff, handoff channels are determined beforehand [3]. Reactive decision handoff decreases number of handoff while proactive decision handoff avoids spectrum sensing time [4].

There are a lot of research article about spectrum handoff, recently [7, 8, 9]. Shiang, and Schaar proposed dynamic channel selection approach for independent wireless users [1]. In order to manage available spectrum resources, information exchange among users is required in their strategy. Wang, and Wang investigate the spectrum handoff schemes for cognitive radio networks [5]. Reactive sensing spectrum handoff, and proactive sensing spectrum handoff is compared in their works. Lertsinsruttavee et al. propose a new spectrum handoff strategy that aims to reduce unnecessary spectrum handoff [6]. In their

works, backup channels are used to avoid consecutive spectrum handoffs. In our work, information exchange is necessary just between secondary users and a secondary base station. Also, we avoid problem of unavailable predetermined channels by exploiting reactive decision spectrum handoff.

In this paper, simulation model of a cognitive radio network that composes of primary users and secondary users is designed. Riverbed Modeler Simulation Software is utilized for simulation scenarios. Because primary users are licensed users, they have right to use their channels at any time without any interruption. Secondary users are designed to make spectrum handoff between time slots of primary users when they are available. Reactive decision spectrum handoff is employed for secondary users with instant spectrum sensing. By using reactive decision spectrum handoff mechanism, repetitive spectrum handoff is avoided.

2. Cognitive Radio Wireless Networks

Cognitive radio is a technology that allows secondary users to exploit spectrum holes in an opportunistic manner [10]. In order to utilize the spectrum, sensing capacity of cognitive radio is used by secondary users. In cognitive radio wireless networks, primary users are licensed users, and secondary users are opportunistic users [11, 12]. Therefore, secondary users utilize licensed channels only when action of primary users is not sensed.

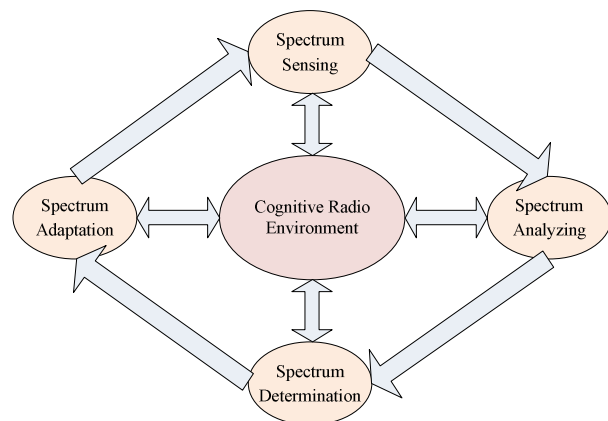


Fig. 1. Implementation steps for cognitive radio networks

In cognitive radio wireless networks, primary networks, and secondary networks share the same geographical area [13]. In Fig. 1, implementation steps for cognitive radio networks are shown. Spectrum sensing is a mechanism that allows secondary users to sense the spectrum holes without obstructing the primary users. Spectrum analyzing is a mechanism that analyzes

the spectrum sensing results. According to analyzed results, best spectrum is decided with the help of spectrum determination. After these steps, secondary users adapt to new channel by means of spectrum adaptation mechanism [14].

2.1. IEEE 802.22 WRAN (Wireless Regional Area Networks)

The IEEE 802.22 WRAN is the first standard that is developed employing cognitive radio techniques by using TV spectrum bands [8]. In IEEE 802.22 systems, unutilized TV spectrum is shared in rural areas. The IEEE 802.22 standard is based on the wide area network infrastructure that determines the function of the physical and medium access control layer [9]. According to this standard, the base station controls communication between the cognitive radio users. Cognitive functions in this standard are based on the principle of dynamic channel management [8, 9].

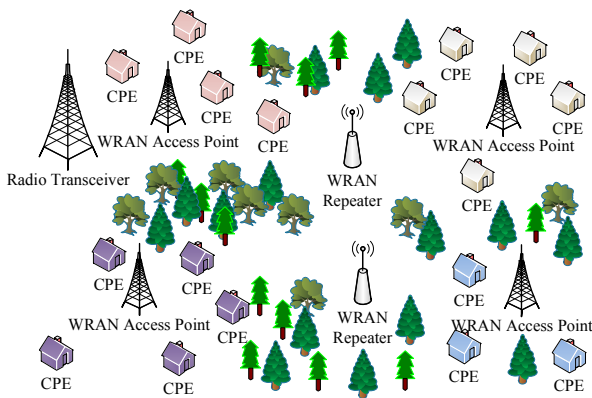


Fig. 2. IEEE 802.22 wireless regional area networks

In the traditional networks such as wireless local area networks and ad-hoc networks, channel management is only interested in the use of resources and quality of service [5]. In cognitive radio network, channel management is also responsible for the protection of the transmission of primary users. The most important task of channel management is protecting primary users from any interference. IEEE 802.22 devices are using cognitive radio capabilities depending on the characteristics of the TV channels [9]. The availability of the television channels is obtained by spectrum sensing mechanism or from an external database. According to information obtained, a list of available channels is formed [8].

In Fig. 2, wireless regional area network environment is shown. There are WRAN access points, WRAN repeaters, CPEs (Customer Premises Equipment), and radio transceiver in IEEE 802.22 WRAN system. CPEs are kind of secondary users in WRAN while repeaters and access points are wireless technology equipment.

2.2. IEEE 802.11af White-Fi

Today, the spectrum bands serve both as licensed and unlicensed. Fixed spectrum allocations are limiting resources because of the increase in number of wireless devices. IEEE 802.11af determines international standards for the sharing of licensed services that use white space spectrum bands such as unlicensed WSDs (White Space Devices), and TVs [7, 8]. Spectrum sharing is done through GDB (Geolocation Data

Base) object by WSDs. IEEE 802.11af standard provides a common architecture and operating mechanism for WSDs [7, 8]. In addition, coverage area of IEEE 802.11af is up to 1 km while reception range of IEEE 802.22 WRAN is up to 100 km [8].

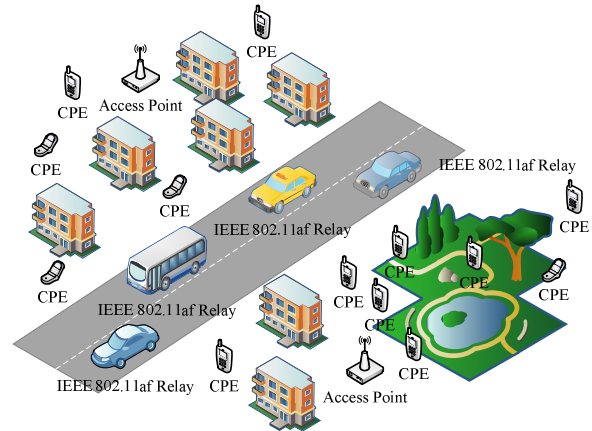


Fig. 3. IEEE 802.11af network environment

In Fig. 3, IEEE 802.11af network environment is shown. IEEE 802.11af protocol is optimized form of IEEE 802.11 protocol [7]. In this protocol, cognitive radio based AP (Access Point) for sharing the TV white space and the STA (Station) is located in the network environment [8]. IEEE 802.11af system consists of three different types of stations; namely fixed, enabling, and dependent. Fixed STA and enabling STA broadcast their registered locations because they are registered STAs [7]. Enabling STA is allowed to give permission to dependent STAs. Enabling STA sends CVS (Contact Verification Signal) after getting current channel condition from TV white space database [8]. CVS is responsible for both validating current channel list, and assuring that dependent STAs are within the coverage area of the enabling STA. DSE (Dynamic STA Enablement) allows dependent STA to exploit current TV channels [7]. Besides, CPM (Channel Power Management) is utilized to update the list of available communication channels as well as changing the frequency and channel bandwidth [8].

2.3. Spectrum Handoff

Secondary users are generally considered as guests to the spectrum due to their having no license [5, 6]. Hence, when the some portion of the spectrum utilized by secondary user is necessary for licensed utilization, the transmission of secondary user needs to be ceased or continue in other available portion of the spectrum [3, 11]. The concept of carrying on transmission in other spectrum band is known as spectrum handoff. Usually, there are three distinct event that spectrum handoff occurs: when action of primary user is detected on the licensed channel, when secondary user lose connection due to the mobility of users, or when present spectrum band cannot support requirements of the applications [12].

Procedure of spectrum handoff occurs depending on two different methods, namely, reactive decision spectrum handoff and proactive decision spectrum handoff [10]. In reactive spectrum handoff, secondary users make spectrum handoff after finding out communication lost. This method necessitates immediate spectrum handoff with no preparation time, and

causes substantial quality degradation for secondary networks [14]. Reactive spectrum handoff is generally used in the instant occurrence of primary users while proactive spectrum handoff is more suitable for the event of user mobility and quality degradation on spectrum bands. In spectrum handoff procedure, two dissimilar priority methods are commonly utilized, namely preemptive, and non-preemptive priority strategies [4]. In preemptive priority strategy, the transmission of the low priority secondary user is interrupted. This strategy is generally used in real time applications [3]. In contrast, the event of spectrum handoff happens after on-going communication of low priority secondary user is finished in non-preemptive priority strategy. Non-preemptive priority strategy is commonly used in applications which do not necessitate instant actions [6].

3. Simulation Model of the Spectrum Handoff Strategy

The Riverbed Modeler simulation software contains various tools such as designing, simulation, and data aggregation [15]. Riverbed Modeler also supports a widespread development environment including the modeling of wireless communication networks, and distributed network systems [15]. In Riverbed, performance of a simulation model is evaluated with the help of discrete event simulations [15]. Moreover, Riverbed Modeler offers a graphical user interface in order to both configure the simulation scenarios, and to develop network models. Configuration of the network is done in three phase; namely network level, node level, and process level. In the network model, topology of the network is constructed. The node level describes the behavior of the node and controls the data flowing in different component of the node. The process level is characterized by state machines that are produced with states and transitions between them. The source code of Riverbed Modeler is based on C programming language [15].

Table 1. Simulation parameters

Parameter	Value
Time slot length of primary users	100 ms
Number of primary users	10
Number of secondary users	3
Receiving frequency of the primary users	1.85 GHz
Transmitting frequency of the primary users	2.4 GHz
Receiving frequency of the secondary users	2.4 GHz
Transmitting frequency of the secondary users	1.85 GHz
Bandwidth of primary and secondary users	2 MHz
Modulation scheme	QPSK
Transmit power of primary and secondary users	0.1 W
Packet inter arrival time of secondary users	0.1 s
Data rate of primary and secondary users	1 Mbps
Packet length of primary users	12 Kb
Packet length of secondary users	10 Kb

In our work, we have used Riverbed Modeler simulation software for developing, modeling, and simulating the proposed wireless network. In our simulation environment, there are 10 primary users and 5 secondary users randomly distributed in the wireless network environment. Free space loss channel propagation model is used for predicting the power of the received packet. Rest of the simulation parameters utilized in the simulation is written in Table 1.

In this paper, a centralized wireless cognitive radio network where primary users and secondary users exist in the same communication environment is designed. Primary users have a license for accessing to the channel while secondary users do not have a license for any channel. So, they only access to the channel opportunistically when it is not occupied by the primary users.

3.1. Simulation Model of the Primary Network

In our work, primary network model is composed of ten primary users and a primary access point in the wireless communication environment. Primary users communicate via their base station using TDMA (Time Division Multiple Access) as a MAC (Medium Access Control) protocol.

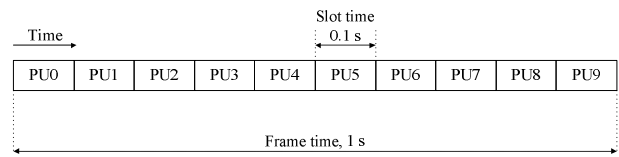


Fig. 4. Slot allocation of primary network for primary users

Fig. 4 depicts slot allocation of primary users for TDMA protocol. In TDMA MAC protocol, time is split into frames and frames are split into time slots. In our work, it is considered that the number of time slots in a frame is equal to the number of primary users that is ten. Hence, a unique time slot is assigned to a primary user for wireless communication. The packet transmission duration of primary users is equal to the length of time slot. Each primary user in the network area is an independent source with a Poisson distribution.

3.2. Simulation Model of the Secondary Network

In our simulation model, cognitive radio network model consists of three secondary users and a secondary base station in the same wireless communication area with the primary users. Secondary users utilize slotted Aloha random access scheme in order to exploit idle time slots of primary users.

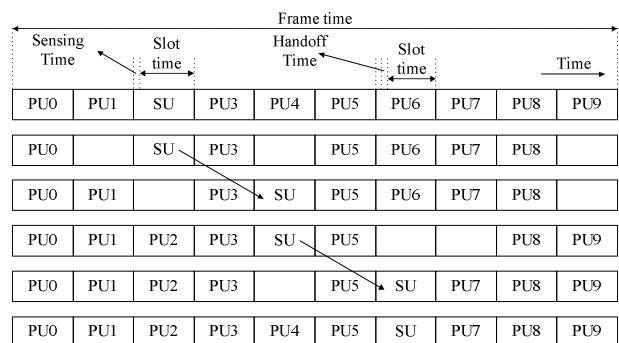


Fig. 5. Spectrum handoff for secondary users

The action of a secondary user in the wireless network area is as follows. A secondary user makes an assessment about the time slot usage in the beginning of each time slot of primary users by spectrum sensing. If the time slot that is exploited until then is idle, secondary user carries on to utilize it. If it is not idle, secondary user attempts to find available time slot. In case

that secondary user finds an available channel, it makes spectrum handoff in order to continue transmission. If secondary user cannot find an available channel, it is necessary for it to cease the transmission and wait for the availability of subsequent time slots.

In Fig. 5, process of spectrum handoff for secondary users is shown. In our cognitive radio wireless network model, it is presumed that each secondary user produces packets with Poisson distribution process. However, the packet length of secondary users is shorter than that of primary users' because of the spectrum sensing time and spectrum handoff time.

4. Simulation Results

In our simulation scenarios, load of primary users is calculated as follows;

$$ptl = 1 / ptit \quad (1)$$

where ptl is terminal load of primary users, and $ptit$ is terminal inter arrival time of primary users.

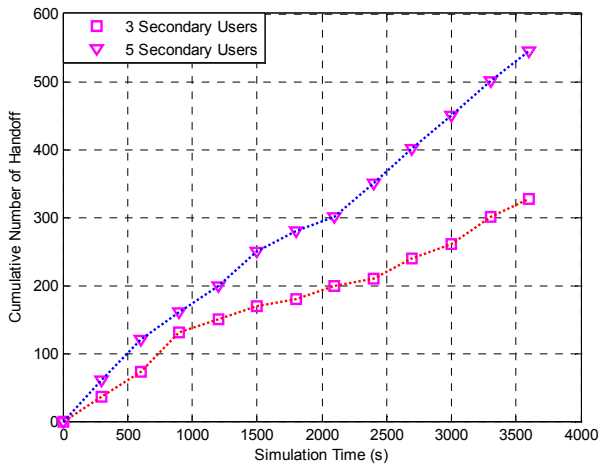


Fig. 6. Number of handoff results when packet inter arrival time of primary users is 1

In Fig. 6, number of spectrum handoff results is shown when packet inter arrival time of primary users is 1. When inter arrival time for packet generation is 1, terminal load of primary users is 1. Then, this means that almost all the time slots are fully occupied by primary users. In this scenario, there are 10 primary users each having infinite buffer. When number of secondary is 3, maximum number of handoff is about 320. And, maximum number of handoff is almost 550 when number of secondary users is 5. As number of secondary users is increased from 3 to 5, the cumulative number of handoff also increases in almost the same rate.

In Fig. 7, cumulative number of spectrum handoff is depicted when packet inter arrival time of primary users is 1.25. When packet inter arrival time is 1.25, terminal load of primary users is 0.8. And, this implies that 0.2 of the time slots are ready to be exploited by secondary users with accurate spectrum sensing mechanism. Besides, probability of spectrum handoff is increased due to the high number of idle time slots. As like first scenario, two different number of handoff results are obtained when number of secondary users is 3, and 5. In simulation scenario, it is seen that cumulative number of handoff is almost

the same in first 1500 seconds of the simulation time because of the inconsistent idle time slots of primary users. All of the simulation results are obtained from Riverbed Modeler simulation software.

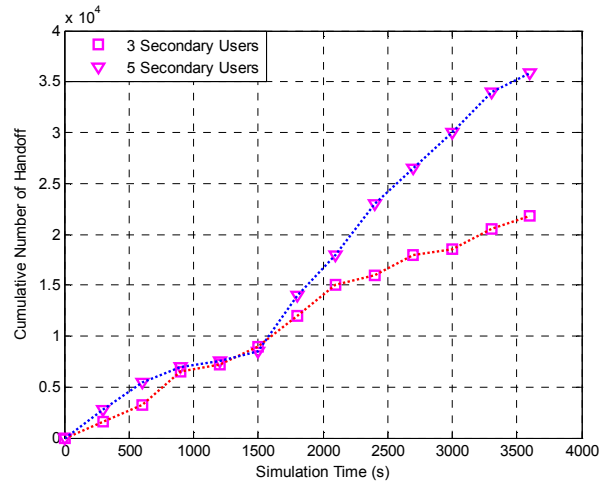


Fig. 7. Number of handoff results when packet inter arrival time of primary users is 1.25

In Fig. 8, throughput of overall network when number of secondary users is 3 is shown. Throughput of the overall network is defined as the number of packet successfully received by both of the base stations. It is clearly seen that throughput of the overall network is about 1 when load of primary users is 1. And, throughput of the overall network is around 0.7 when load of primary users is 0.8. In this case, 0.2 of all the time slots of primary users can be exploited by secondary users. The curve where load of primary users is 0.8 without spectrum handoff mechanism is given for comparison. By means of spectrum handoff, overall network throughput is improved from about 0.6 to around 0.7 when load of primary users is 0.8.

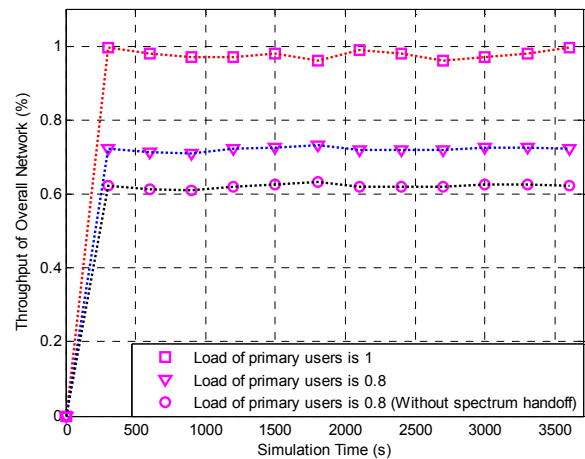


Fig. 8. Throughput of overall network when number of secondary users is 3

5. Conclusions

In this work, we have simulated a slotted Aloha based secondary network, and analyzed cumulative number of

spectrum handoff. Primary users and secondary users share the time slotted based common communication environment. Primary users are licensed to access their time slots and employ TDMA as a MAC scheme. Secondary users utilize slotted Aloha as a random access technique and access to the time slots when they are not employed by the primary users. An example wireless cognitive radio network scenario has been designed, modeled and simulated by utilizing the Riverbed Modeler simulation software. Secondary users are developed to make spectrum handoff among time slots of primary users with reactive decision spectrum handoff process. This work has also revealed that the throughput of overall cognitive radio network can be improved by means of making spectrum handoff within idle time slots of primary users.

Acknowledgment

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6. References

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