Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 2, Number 4 January-March (2015) pp. 341-346
© Krishi Sanskriti Publications
http://www.krishisanskriti.org/areee.html

Optimal Power Allocation for Hybrid Spectrum Sharing in Cognitive Radio Networks

Ramchandrappa[1], Akash[2], Prakash[3] and Kailas[4]

[1,2,3,4] *Department of Electronic & Communication Engineering Veerappa Nisty Engineering College, Shorapur-585220*
E-mail: [1]ramchandracpatil@gmail.com, [4]kailas.uttara@gmail.com

Abstract—*In this project, To consider power allocation in multiband cognitive radio (CR) networks, where multiple secondary users (SUs) transmit via a common relay and compete for the transmit power of the relay .I employ a hybrid overlay/underlay spectrum sharing scheme, allowing the SU to adapt its way of accessing the licensed spectrum to the status of the primary user (PU). If the PU is detected to be idle at the selected channel, the SU works in an overlay mode; else, it works in spectrum underlay.*

In addition, an auction-based power-allocation scheme is proposed to solve power competition of multiple SUs. For the SU working in spectrum overlay, the relay allocates the power in proportion to its payment without additional constraints; for the SU in spectrum underlay, its own transmit power and that of the relay is upper bounded for the quality of service (QoS) of the PU. Then, the convergence of the proposed auction algorithm and the outage probability of secondary transmissions are theoretically analyzed. Finally, the performance of the proposed scheme is verified by the simulation results.

Key words: *Auction game, cognitive radio (CR), hybrid spectrum sharing, outage probability, power allocation.*

1. INTRODUCTION

With the rapid deployment of wireless services over the last decade, the radio spectrum is becoming a valuable and scarce resource. How to support growing applications with limited spectrum resources emerges as a critical issue for future wireless communications. On the other side, the report from the Federal Communications Commission reveals that most of the licensed spectrum is severely underutilized [1]. As a promising technique, cognitive radio (CR) [2], [3] is proposed to deal with the dilemma between spectrum scarcity and spectrum under utilization .CR allows unlicensed users [referred to as secondary users (SUs)] to access licensed bands under the condition that the induced interference to the licensed users [referred to as primary users (Pus)] does not reach an unacceptable level.

The term Cognitive Radio was firstly described by Joseph Mitola [1]. From his description can define the Cognitive Radio as a radio capable of analyzing the environment (as channels and users), learning and predicting the most suitable and efficient way of using the available spectrum and adapting all of its operation parameters [1-3]. The main reason for introducing the cognitive radio is the inefficient use of the radio resources and particularly the spectrum. Spectrum sensing is an essential functionality of CRs. The aim of spectrum sensing is to find opportunities for agile use of spectrum. In general, there are two sensing modes, reactive sensing and proactive sensing, depending on the way to initiate the sensing. *Reactive sensing:* The sensing is initiated only when the user has data to send, thus it is called on-demand sensing. If no usable channel was found, the user will wait for a predefined time and then restart sensing again until the user send all data that he was trying to send. *Proactive sensing:* The sensing is done periodically even when the user is not intending to send any data. The time between the sensing iteration is called the sensing period.

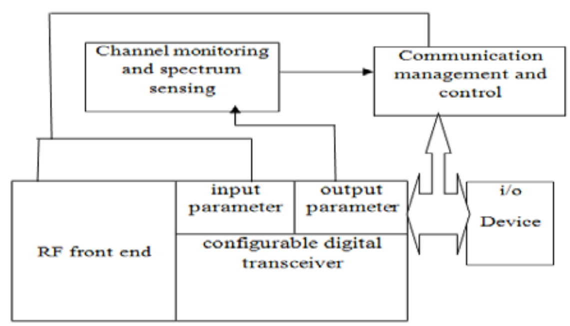


Fig. 1: block diagram of cognitive radio network

It consists of three basic building blocks:

1. Digital Transceiver.
2. Channel monitoring and spectrum sensing module.
3. Communication management and control.

Digital Transceiver: The main components of a cognitive radio transceiver are: RF front-end and Baseband processing unit. In the RF front-end, the received signal is amplified, mixed and then converted from analog to digital by using A/D converter. In the baseband processing unit, the signal is modulated/demodulated and encoded/decoded. RF hardware for the cognitive radio should be capable of tuning to any part of a large range of frequency spectrum.

RF Front-End: It consists of following blocks:
RF filter: The RF filter selects the desired band from received RF signal by using band-pass filter.
Low noise amplifier (LNA): It amplifies the desired signal and at the same time it minimizes noise components.
Mixer: It mixes, the received signal with locally generated RF frequency and converted to the baseband or the intermediate frequency (IF).
Voltage-controlled oscillator (VCO): It is used to converts the incoming signal to baseband or an intermediate frequency.
Phase locked loop (PLL): The PLL ensures that a signal is locked on a specific frequency and can also be used to generate precise frequencies with fine resolution.
Channel selection filter: It is used to select the desired and reject the adjacent unused channels.
Automatic gain control (AGC): The AGC maintains the gain or output power level of an amplifier. The cognitive radio network can be used efficiently in network centric, distributed, ad-hoc, mesh architecture, and serve the needs of both licenced and unlicenced applications. The basic components of cognitive radio network are mobile station, base station and backbone networks depending on this there are three kinds of network architecture in cognitive radio i.e, Infrastructure, ad hoc and mesh architecture.
In general, an SU has three spectrum sharing approaches:

1. Opportunistic spectrum access (also known as spectrum overlay) [4], under which a SU accesses a band only when It is not being used by the PU;
2. Spectrum sharing (also known as spectrum underlay) [5], where the SU coexists with the PU and transmits with power constraints to guarantee the quality of service (QoS) of the PU; and
3. Sensing-based spectrum sharing [6], with which the SU first senses the status of the PU (idle/active) and then selects an appropriate spectrum sharing mode based on the sensing result. If the PU is detected to be active, the SU selects the spectrum underlay mode and transmits with lower power. Otherwise, the SU works at spectrum overlay and transmits with its maximum power budget for a higher data rate.

In such hybrid overlay/underlay scheme, the SU can transmit in both the idle and busy bands. It improves the throughput of the secondary network while maintaining a harmless interference to the PU. In this paper, to study distributed power allocation for Sus in hybrid CR networks, where multiple Sus simultaneously transmit under different spectrum sharing modes with the help of a common relay and compete for the relay's transmit power.

- **Primary users:** these wireless devices are the primary license-holders of the spectrum band of interest. In general, they have priority access to the spectrum, and subject to certain Quality of Service (QoS) constraints which must be guaranteed.
- **Secondary users:** these users may access the spectrum which is licensed to the primary users. They are thus secondary users of the wireless spectrum, and are often envisioned to be cognitive radios. For the rest of this chapter, to will assume the secondary users are cognitive radios (and the primary users are not) and will use the terms interchangeably. These cognitive users employ their "cognitive" abilities to communicate while ensuring the communication of the primary users is kept at an acceptable level1.

2. WORK OVERVIEW

In [1] Power allocation in multi user orthogonal frequency division multiplexing based cognitive radio network is considered overlay/underlay mode not considered. In[2]Resource allocation in multiband cognitive radio for underlay/overlay mode spectrum sharing scheme, allowing the secondary user to adapt its way of accessing the licensed spectrum to the status of primary user. Resource allocation for real-time and non-real-time services is not employed. In [3] consider the channel uncertainty of link between primary user and secondary user, also proposed a method to optimization problem which yields better results for non-real-time user's resource allocation .The problem of resource allocation for real-time user not addressed.

Cognitive radio (CR) and opportunistic spectrum sharing are promising concepts for boosting the efficiency of radio spectrum utilization. In the last decade, research on CR has therefore focused on three main spectrum sharing paradigms: underlay, overlay, and interweave [13]. Each of them requires a different level of cognition about the surrounding environment and a different level of sophistication which leads to different challenges.

Underlay and overlay CR systems and specialize to the scenario where a primary transmitter/ receiver pair is willing to share its spectrum with a secondary transmitter/receiver pair, given that the primary rate requirements are satisfied. The most common information theoretical model for underlay CR is the interference channel (IC). The (two-user) IC describes the situation where two independent transmitter receiver pairs communicate interfering each other. In addition to classical coding strategies for the IC .several authors have studied this scenario with CR constraints.

In particular, multiple-antenna transmit strategies are of special interest for underlay scenarios where interference to the primary receiver must not exceed a given level. Assuming that sufficient channel state information is available at the secondary transmitter, beam forming techniques can be used to control the interference to the primary receiver while maximizing the secondary rate (see e.g. [16], [17]). For the special case of a multiple-input/single-output (MISO) secondary system coexisting with a single-input/single-output

(SISO) primary system, I investigated in [19] gains in secondary rate that can be obtained by spatial shaping. Showed furthermore that additional gains can be obtained in this setting if rate splitting is used at the secondary transmitter and successive decoding (including the interfering primary message) is performed at the secondary receiver.

Components of Cognitive Radio Network

With the development of CR technologies, secondary users who are not authorized with spectrum usage rights can utilize the temporally unused licensed bands owned by the primary users. Therefore, in CR network architecture, the components include both a primary network and a secondary network.

Primary Network*:* The primary network (or licensed network) is referred to as an existing network, where the primary users have a license to operate in a certain spectrum band. If primary networks have an infrastructure, primary user activities are controlled through primary base stations. Due to their priority in spectrum access, the operations of primary users should not be affected by secondary users.

Secondary Network*:* The CR network (also called the dynamic spectrum access network, secondary network) does not have a license to operate in a desired band. Hence, additional functionality is required for CR users to share the licensed spectrum band. CR network also can be equipped with CR base stations that provide single-hop connection to CR users. Finally, CR networks may include spectrum brokers that play a role in distributing the spectrum resources among different CR networks.

Spectrum Broker*:* If several secondary networks share one common spectrum band, their spectrum usage may be coordinated by a central network entity, called spectrum broker. The spectrum broker collects operation information from each secondary network and allocates the network resources to achieve efficient and fair spectrum sharing.

The three types of cognitive behavior are:

- Interference avoiding behavior (spectrum interweave): the secondary users employ the primary spectrum without interfering with the primary users whatsoever. The primary and secondary signals may be thought of as being orthogonal to each other: they may access the spectrum in a Time- Division-Multiple-Access (TDMA) fashion, in a Frequency-Division-Multiple-Access (FDMA) fashion, or in any fashion that ensures that the primary and secondary signals do not interfere with each other.
- Interference controlling behavior (spectrum underlay): the secondary users transmit over the same spectrum as the primary users, but do so in a way that the interference seen by the primary users from the cognitive users is controlled to an acceptable level. This acceptable level is captured by primary QoS constraints .This is termed *underlay* as often the cognitive radios transmit in such a fashion that they appear to be noise under the primary signals. The cognition required is knowledge of the “acceptable levels” of interference at primary users in a cognitive user’s transmission range as well as knowledge of the effect of the cognitive transmission at the primary receiver.
- Interference mitigating behavior (spectrum overlay): the secondary users transmit over the same spectrum as the primary users but in addition to knowledge of the channels between primary and secondary users (nature), the cognitive nodes have additional information about the primary system and its operation. Examples are knowledge of the primary users’ codebooks, allowing the secondary users to decode primary users’ transmissions, or in certain cases even knowledge of the primary users’ message [31].

The radio spectrum is becoming a valuable and scarce resource with the rapid deployment of wireless services over the last decade or so .The support for growing applications with limited spectrum resources emerging as a critical issue for future wireless communications.

The FCC reveals that most of the licensed spectrum is severely underutilized. Hence, as a promising technique Cognitive Radio (CR) is been proposed to deal with the spectrum scarcity and spectrum underutilization. CR allows unlicensed users to access licensed bands under the condition that induced interference to the licensed users does not reach an unacceptable level.

In this paper, To consider power allocation in multi- band cognitive radio (CR) networks, where multiple secondary users (SUs) transmit via a common relay and compete for the transmit power of the relay. A hybrid overlay/underlay spectrum sharing scheme, allowing the SU to adapt its way of accessing the licensed spectrum to the status of the primary user (PU) has been employed. If the PU is detected to be idle at the selected channel, the SU works in an overlay mode; else, it works in spectrum underlay. In addition, an auction-based power-allocation scheme is proposed to solve power competition of multiple SUs thereby overcoming the drawbacks of pre-existing technologies.

The main objective is the consideration of power allocation in multiband cognitive radio (CR) networks, where multiple secondary users (SUs) transmit via a common relay and compete for the transmit power of the relay. A hybrid overlay/underlay spectrum sharing scheme is adapted, allowing the SU to adapt its way of accessing the licensed spectrum to the status of the primary user (PU). If the PU is detected to be idle at the selected channel, the SU works in an overlay mode; else, it works in spectrum underlay.

In addition, an auction-based power-allocation scheme is proposed to solve power competition of multiple SUs. For the SU working in spectrum overlay, the relay allocates the power in proportion to its payment without additional constraints; for the SU in spectrum underlay, its own transmit power and that of the relay is upper bounded for the quality of service (QoS) of the PU. Then, the convergence of the proposed auction algorithm and the outage probability of secondary transmissions are theoretically analyzed. Finally, the performance of the entire proposed scheme is verified by means of simulation.

3. METHODOLOGY

Our main contributions are summarized as follows.

1. A hybrid overlay/underlay spectrum sharing scheme is employed for multiband CR networks, where the SU adapts its way of accessing the licensed spectrum to the status of the PU. If the PU is idle at the channel selected by the SU, the SU works in an overlay mode; otherwise, the SU works in spectrum underlay, under which its transmit power and relay power are constrained to avoid causing harmful interference to the PU.
2. A distributed power bidding and allocation algorithm for relay-assisted secondary transmissions is explicitly developed for multi-user CR networks.
3. The outcome of the proposed auction game is investigated, and the existence of a unique NE is theoretically proven.
4. In the proposed hybrid system, the SU would have different outage probability in different spectrum sharing modes, which is difficult to be directly derived from the existing results. In this paper, to provide theoretical analysis of outage probability for a hybrid spectrum sharing system, which supports the SUs working in two modes, coexisted.

Along with this network model and basic assumptions are being presented followed by description of a power auction mechanism for multi-user CR networks and analyzes its convergence performance. The outage probability of secondary transmissions is theoretically analyzed. Along with numerical results.

In this project, to address the power-allocation problem in hybrid overlay/underlay CR networks, where multiple SUs transmit via a common relay and compete for the transmit power of the relay.

First, to propose a relay power-allocation scheme on the basis of an auction game, in which the relay organizes an auction for selling it's transmit power, whereas the SU acts as the player and bids for a maximum utility.

Second, the mathematically prove the convergence [i.e., the convergence to a unique Nash equilibrium (NE)] of the proposed auction algorithm.

Finally, it derive the closed form of the outage probability for both spectrum sharing modes.

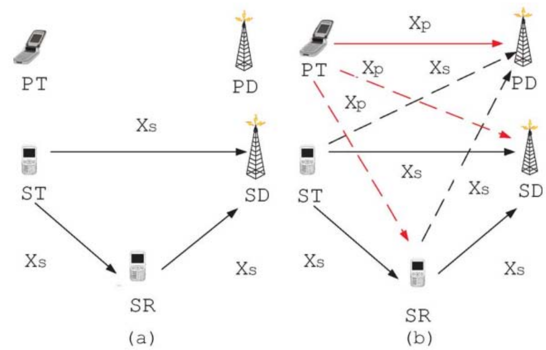


Fig. 2: Network Model

Overall flow of this project:

1. A hybrid overlay/underlay spectrum sharing scheme is employed for multiband CR networks, where the SU adapts its way of accessing the licensed spectrum to the status of the PU. If the PU is idle at the channel selected by the SU, the SU works in an overlay mode; otherwise, the SU works in spectrum underlay, under which its transmit power and relay power are constrained to avoid causing harmful interference to the PU.
2. A distributed power bidding and allocation algorithm for relay-assisted secondary transmissions is explicitly developed for multiuser CR networks.
3. The outcome of the proposed auction game is investigated, and the existence of a unique NE is theoretically proven.
4. In the proposed hybrid system, the SU would have different outage probability in different spectrum sharing modes, which is difficult to be directly derived from the existing results. In this project, to provide theoretical analysis of outage probability for a hybrid spectrum sharing system, which supports the SUs working in two modes, coexisted.

Power auction mechanism involves following algorithm for power bidding and allocation:

Step1. Request for cooperation
ST*i*: sends a request to the relay for cooperation.
SR: responds the cooperation request of ST*i*.
ST*i*: transmits the data in the first phase.
SR: If the received signals cannot be successfully decoded, it informs ST*i* of the failure; else, it allows ST_ ST*i* to participate in the auction and goes to Step 2.
Step2. Initialization
ST*i*: initializes the required power *Pri* (0) to $\hat{P}_{r4}$, *calculates* the original bid *fi*(0) by, and then submits these values to the relay.

Step3. Power Allocation
SR: updates the allocated power *Pri* (t + 1) for all the STs, then informs the STs.
Step4. Bid Update
ST*i*: updates its bid *fi*(t + 1) according to (27) and sends it back to the relay.
Step5. Convergence
Repeat Step 3 and Step 4, until the value of *fi*(t) no longer changes with additional iterations.
Outage Probability:
Without loss of generality, to consider that an outage of secondary transmissions occurs when SD*i* fails to recover the information from ST*i*. In this project, to assume that the SR assists the ST transmissions by DF protocol. If the SR fails to decode the STs signal, i.e., the outage of the transmissions from the ST to the SR occurs, the SR cannot help the ST at the moment.

Thus, the ST would not participate in the current auction. Only the ST whose data are successfully decoded at the SR is allowed to join the auction. Here, to investigate the impact of the proposed relay power-allocation scheme on the performance of the outage probability of secondary transmissions (secondary outage probability). Thus, consider the outage of the transmissions from the SR to the SD and assume that the transmission from the ST to the SR has not suffered the outage.

For overlay and underlay mode, the mutual information between the ST and the SD are defined, respectively, as

$$I_i^{00} = \frac{1}{2}\log_2(1+\Gamma_i^{00}(1)+\Gamma_i^{00}(2))$$

$$I_i^{10} = \frac{1}{2}\log_2(1+\gamma_i^{10}(1)+\gamma_i^{10}(2))$$

Meanwhile, the mutual information between the ST and the SR are defined, respectively, as

$$I_{r4}^{00} = \frac{1}{2}\log_2\left(1+\frac{P_i\,|G_{ST_4}^{SR}|^2}{\sigma^2}\right)$$

$$I_{r4}^{10} = \frac{1}{2}\log_2\left(1+\frac{P_i^{'}\,|G_{ST_4}^{SR}|^2}{P_u\,|G_{PT}^{SR}|^2+\sigma^2}\right)$$

4. SIMULATION RESULTS

Here, we present simulation results to demonstrate the performance of the proposed power-allocation algorithm. We first consider a scenario where two secondary links ($a1 \rightarrow b1$, $a2 \rightarrow b2$) attempt to access the spectrum of the PU. The channel gains are (0.097/$d\alpha$)1/2, where d is the distance between two nodes, and the path-loss exponent is α = 4. Without a special specification, the transmit power budget of each ST is set to 0.01 W, the transmit power of the PU is 0.01 W, the total power of the relay is Pr = 0.2 W, and the noise variance is σ2 = 10−13.

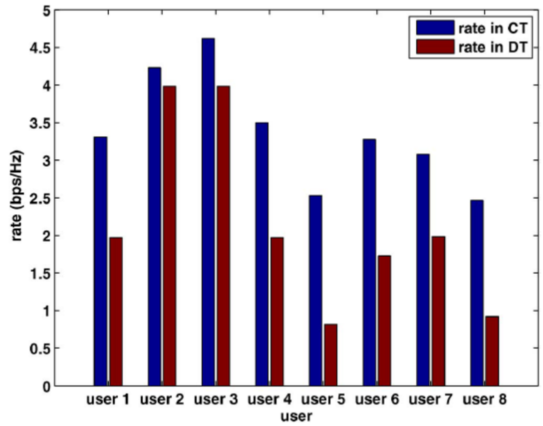
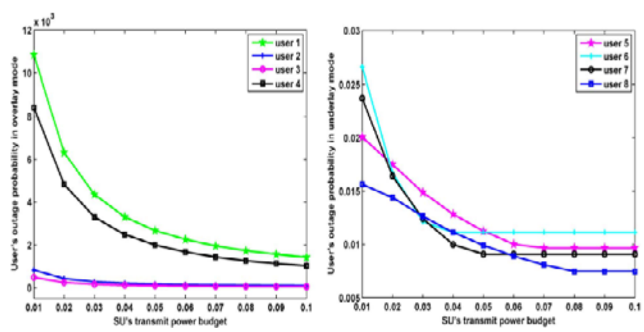


Fig. 3: User rate in CT and DT.

Finally, we demonstrate the performance of the secondary outage probability.

We consider the relationship of the secondary outage probability and the ST's transmit power budget *Pi*. The threshold R is set to 1, the minimum rate *R*req of the PU is 0.4, and the ST's transmit power budget *Pi* varies within the range (0.01 W, 0.1 W). Fig. 10(a) shows the variations of the outage probability of user $a1-a4$ who are working in overlay mode. It is observed, for a given rate R, that the outage probability of these four users decrease with the increase in their transmit power. Thus, the larger the transmit power, the higher data rate the user can achieve, and the smaller the outage probability will be.



5. CONCLUSION

Sensing-based spectrum sharing combines the benefits of both spectrum overlay and spectrum underlay to improve the throughput of the SU, without generating harmful interference to the PU. In this paper, we have tackled the power-allocation problem for relay-assisted secondary transmissions in a hybrid overlay/underlay spectrum sharing CR network, where the Sus join the power auction organized by the relay and bid for maximizing the utility. The auction algorithm and its convergence performance are investigated. Future work can be extended to the cases with imperfect spectrum sensing and will find a way to mitigate the interference between the PU and the SUs.

REFERENCES

[1] "Spectrum Policy Task Force Report ET Docket,"Washington, DC, Tech. Rep. 02-155, Nov. 2002.
[2] J.Mitola and G. Q.Maguire, Jr., "Cognitive radio: Making software radios more personal," *IEEE Pers. Commun.*, vol. 6, no. 4, pp. 13–18, Aug. 1999.
[3] S.Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE J. Sel. Areas Commun.*, vol. 23, no. 2, pp. 201–220, Feb. 2005.
[4] Q. Zhao and B. M. Sadler, "A survey of dynamic spectrum access," *IEEE Signal Process. Mag.*, vol. 24, no. 3, pp. 79–89, May 2007.
[5] L. Le and E. Hossain, "Resource allocation for spectrum underlay in cognitive radio networks," *IEEE Trans. Wireless Commun.*, vol. 7, no. 12, pp. 5306–5315, Dec. 2008.
[6] Y. Kang, Y. C. Liang, H. K. Garg, and L. Zhang, "Sensing-based spectrum sharing in cognitive radio networks," *IEEE Trans. Veh. Technol.*, vol. 58, no. 8, pp. 4649–4654, Oct. 2009.
[7] V. Chakravarthy, X. Li, R. Zhou, Z. Wu, and M. Temple, "A novel hybrid overlay/underlay cognitive radio waveform in frequency selective fading channels," in *Proc. Int. Conf. CROWNCOM*, 2009, pp. 1–6.
[8] J. Oh and W. Choi, "A hybrid cognitive radio system: a combination of underlay and overlay approaches," in *Proc. IEEE Int. Conf. Veh. Technol.*, 2010, pp. 1–5.
[9] X. Bao, P. Martins, T. Song, and L. Shen, "Capacity of hybrid cognitive network with outage constraints," *IET Commun.*, vol. 5, no. 18, pp. 2712– 2720, Dec. 2011.
[10] T. Qiu,W. Xu, T. Song, Z. He, and B. Tian, "Energy-efficient transmission for hybrid spectrum sharing in cognitive radio networks," in *Proc. IEEE Int. Conf. Veh. Technol.*, May 2011, pp. 1–5.