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Spectrum Handoff in Cognitive Radio Networks: A Survey

Dr. NISAR A. LALA*, ALTAF A. BALKHI and G. M. MIR

Division of Agricultural Engineering, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir Srinagar, J&K, India.

Abstract

Cognitive radio (CR) is a promising solution to improve the spectrum utilization by enabling unlicensed users to exploit the spectrum in an opportunistic manner. Spectrum handoff is a different type of handoff in CR necessitated by the reappearance of primary user (PU) in the licensed band presently occupied by the secondary users (SUs). Spectrum handoff procedures aim to help the SUs to vacate the occupied licensed spectrum and find suitable target channel to resume the unfinished transmission. The purpose of spectrum mobility management in cognitive radio networks is to make sure that the transitions are made smoothly and rapidly such that the applications running on a cognitive user perceive minimum performance degradation during a spectrum handoff. In this paper, we will survey the literature on spectrum handoff in cognitive radio networks.

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Introduction

The spectrum is a precious electromagnetic resource and is regulated by governmental agencies in order to manage complex issues. Presently, spectrum is allocated by fixed allocation policy in which transmission power is regulated and different frequency bands are assigned for different services and applications. There has been tremendous growth of wireless users and applications over the last decade. The total number of users worldwide were 3.2 billion in 2009 and it was projected to increase by 100 folds by 2013[1]. These new applications require more spectrum allocation and it becomes difficult to find unallocated spectrum as most of the spectrum bands stands already allocated by fixed allocation policy. This policy has created a situation where there appears an artificial scarcity of the spectrum. But the survey of Federal Communications Commission (FCC)[2] spectrum task force reported the utilization of the allocated spectrum varies from 15% to 85% and is a function of space and time. Other spectrum occupancy measurements conducted have revealed that the average utilization in New York City[3] was at 5.2% while in Chicago[4] at 17.4%. Several other countries spectrum occupancy measurement studies[5,10] also confirmed that

CONTACT Dr. NISAR A LALA lalanisar_ae@rediffmail.com Division of Agricultural Engineering, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir Srinagar, J&K, India.

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spectrum is heavily under-utilized at this moment. Thus, the persistent increase in demand of spectrum cannot be fulfilled unless an alternate scheme to regulate the scarce spectrum in not found. This new scheme is the dynamic spectrum access (DSA)[11,13] wherein cognitive (or secondary) users are allowed to opportunistically utilize the idle licensed bands, referred to as spectrum hole or white space, without interfering with the existing (or primary) users. If spectrum is utilized on time or frequency basis, the spectrum opportunities appear in the form of holes. In time domain, it is the period of time during which the primary user in not transmitting and in frequency domain, it is the frequency band in which secondary user can transmit without interference to primary user. The enabling technology of the DSA is the cognitive radio (CR). According to Haykin[14], the cognitive radio is defined as an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- Highly reliable communications whenever and wherever needed.
- Efficient utilization of the radio spectrum.

Cognitive radio has two important capabilities: cognitive capability and reconfiguration. Cognitive capability enables the CR to sense its radio environment in order to find spectrum holes. These spectrum holes will be utilized to communicate wherever and whenever needed, thus increasing spectrum utilization.

Reconfigurability is the capability of adjusting operating parameters for the transmission on the fly without any modifications in the hardware components and thus, enable the cognitive radio to adapt easily to the dynamic radio environment. The reconfigurable parameters are operating frequency, modulation and transmission power etc.

Functions of Cognitive Radio

The main purpose of the cognitive radio is to realize dynamic access to the idle spectrum in order to have communication. However, implementation of a cognitive radio is a challenging task. A typical cognitive radio scenario consists of secondary users (SUs) which co-exist with the primary users (PUs). PU has a priority to use the spectrum as they have legacy rights for the spectrum access. SU opportunistically access the spectrum when they find primary user is not using the spectrum or underlay access to the spectrum, when both PU and SU co-exist, with strict constraint over non-interference among the users. The development of cognitive radio technology is still at an early stage due to multitude of challenges and these issues need to be addressed rigorously before a practical cognitive radio network is realized. The main functions of cognitive radio are classified as under[13]:

- Spectrum Sensing
- Spectrum Management
- Spectrum Sharing
- Spectrum Mobility

Spectrum Sensing

Spectrum sensing is the important function of the cognitive radio. The cognitive user (or SU) has to sense the radio environment in order to detect the idle spectrum (or spectrum hole) and use that idle spectrum for its communication. The sensing operation should also be able to detect the PU's arrival on the frequency band, presently occupied by SUs, instantly and accurately[15].

Spectrum Management

Spectrum management helps in acquiring the best spectrum hole for the transmission of SU among large number of available spectrum holes. The SU has to interact with different protocol layers of the network to maintain the QoS of an application. Based on the availability of the spectrum, the channel is allocated to the SU. This decision also depends on the internal and external policies as well as other regulatory issues of the spectrum. The spectrum management functions can be classified as under:

Spectrum Analysis

The spectrum analysis performs the function of the characterization of the idle spectrum found through the spectrum sensing. The characterization of holes is necessary due to availability of very wide range of spectrum for its operation. The characteristics, such as interference, path loss, wireless link errors, link layer delay etc., varies with change in operating frequencies[13].

Spectrum Decision

As per the requirement of the CR user, the appropriate spectrum band is selected for the transmission that satisfies the quality of service (QoS) of the SU.

Spectrum Sharing

Spectrum sharing is an important functionality of cognitive radio as it coordinates the traffic between secondary and primary users. It is a challenging task as it requires high degree of cooperation, understanding and coordination between primary and secondary users.

Spectrum Mobility

Spectrum mobility refers to the changing the frequency band during data transmission due to arrival of PU on that band. The SU has to switch to another frequency band which is not used by the PU at that time in order to continue the transmission[16]. The switching to this idle band should be seamless so that there is minimum QoS degradation of the application running on the SU. As soon as the PU needs the frequency band, the SU has to terminate its transmission and free the frequency band for the PU functioning[17].

Handoff Requirements

The temporary service disruption occurs during handoff which will influence the QoS of the communication. The necessary requirements to reduce the adverse effects of handoff are[18]:

- The latency of the handoff should be very low. The transfer from the current band of communication to new band should be very fast so that the disruption period is reduced to minimum.
- There should be minimum effect on the QoS. The functions of spectrum sensing, analysis and decision should be performed quickly in order to minimize the call dropping probability.
- The number of handoffs/unit time (or handoff rate) should be minimum. The handoff process disrupts the communication temporarily so reduction in number of handoffs per unit time will reduce the overall disruption period.
- The additional signalling during the handoff process should be minimum.

Handoff Issues In Cognitive Radio Networks

In addition to the issues related to handoff in other wireless networks, the cognitive radio has the new challenge of spectrum mobility. Therefore, the solutions available in the literature for other wireless networks cannot be applied to cognitive radio due to absence of fixed spectrum allocation. The other challenge is due to the availability of the very wide range of spectrum for transmission. The channel characteristics change with change in operating frequency that depends on the idle band found. In this section, we will provide the survey of previous research works for important function of spectrum handoff.

The important issue of modeling the spectrum handoff in presence of multiple interruptions due to arrival of primary users was analyzed in[17,19-21]. For the analysis of spectrum handoff, two approaches were adopted in research literature depending on the timing of the selection of the channels to be used at the time of handoff. The first approach is the proactive-decision approach[22-25] in which the channels to be used for future handoff is decided before actual handoff. The channel selection is based on the use of prediction techniques. The second approach is the reactive decision approach[26-28] in which the channels are selected after handoff request is made through instantaneous sensing of the spectrum. Comparative study of the two approaches is provided in[29] which discussed their advantages and disadvantages. In[30] hybrid spectrum handoff algorithm is proposed in which the algorithm switches between proactive and reactive approaches depending upon the primary arrival rate with the aim to reduce the service time of the SU. The authors of[31] presented the analysis of handoff for opportunistic and negotiated situations in terms of four metrics such as link maintenance probability, number of handoffs, non-completion probability and switching delay. The authors of [32,33] proposed characterization of PUs and SUs by assuming an exponential traffic distribution model. The authors of[32] analyzed the impact of channel reservation on handoff while[34] studied the forced termination probability, blocking probability and throughput by assuming fixed, truncated exponential, truncated lognormal and truncated pareto traffic distribution models. The authors of[35] proposed a metric such as overall system time with the aim to minimize it in order to support better QoS of secondary communication. The concept of spectrum pooling was proposed to cognitive radio[36] in order to realize a real time handoff while[37] proposed the division of spectrum pool into two parts i.e. inside and outside bands. When inside bands reduce below a threshold value, the outside band is sensed to find idle spectrum and[38] proposed the concept of second receiver in addition to spectrum pool in order to support real time handoff. The authors of[39] proposed combined optimization of spectrum sensing and handoff in order to obtain improvements in both functions and realize a fast handoff while[40] proposed the cooperative sensing of secondary user group and admission control for multiuser scenario. By adopting that policy there was an increase in accuracy of PU's detection probability, reduction in probability of missed detection and false alarm thus, resulted in increased efficiency of the spectrum handoff. The authors of[41] proposed a voluntary handoff in which the SUs handoff voluntarily to another idle channel before PU's detection on that channel in order to reduce disturbance during handoff and at the same time minimize handoff delay which reduced to switching delay only while[42] proposed selection of target channel sequence decided proactively so that the handoff failure rate is reduced. The authors' of[43] proposed an algorithm based on time estimation which determined the remaining idle period of the channels and schedules channel usage in advance. The proposed approach reduced the disruption to PUs and at the same time increased channel utilization. The authors' of[44] considered the practical limitation of sensing reliability and sensing time and determined the optimal channels by utilizing partially observable markov decision process to reveal the network information by partially sensing the available channels without the necessity of obtaining correct channel information. The proposed algorithm selected the optimal channels for handoff with minimum waiting time while[45] proposed an algorithm for sensing and selecting channels having maximum probability of appearing idle using traffic prediction technique that resulted in reduction of the corresponding sensing time. The authors' of[46] proposed to switch from overlay to underlay mode by reducing the transmission power upon PU's arrival under the non-interference constraint and proposed a multi-cell spectrum handoff in order to overcome the coverage issue of underlay mode while[47] proposed compromise decision either to stay or change channels during handoff depending on the delay bound requirement of the flow. The proposed algorithm used the cumulative probability based on past backlog measurements in order to take the handoff decision.

Fuzzy logic was applied to handoff[48,49] which did two important functions, the power modification and intelligent handoff decision based on the information of interference, transmission power and required data-rate. In[50] , the new parameter such as holding time of the channel is included into decision making so that the channel having larger idle period among the available idle channels is selected for transmission after handoff. As a result, there is considerable reduction in handoff rate. There are few works on cognitive adhoc networks that utilize spectrum handoff. The authors' of[51] studied the impact of user mobility and PU's arrival on the spectrum handoff rate and session continuity distribution. The works[52-54] applied proactive decision approach for handoff in cognitive adhoc networks and[55] provided the characterization of spectrum handoff using three dimensional discrete time markov chain and analyzed the effect of different channel selection schemes on the performance of handoff.

Conclusion

Spectrum is a valuable natural resource in this information age. Considering the difference between spectrum efficiency and utilization, novel spectrum management techniques are under study for addressing future needs. The promising solution is the cognitive radio. However, spectrum mobility and handoff are new challenges for CR networks. The spectrum handoff is an important operation to support resilient and continuous communication. In this paper, we surveyed a number of such challenges and presented number of solutions with main focus on spectrum handoff. These issues need to be addressed before a practical cognitive radio network is realized.

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