Simulation Modelling Practice and Theory 19 (2011) 1723–1744

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

# A cross-layer protocol of spectrum mobility and handover in cognitive LTE networks

Yuh-Shyan Chen [a,*], Ching-Hsiung Cho [a], Ilsun You [b], Han-Chieh Chao [c,d,e]

[a] Department of Computer Science and Information Engineering, National Taipei University, Taipei, Taiwan, ROC
[b] School of Information Science, Korean Bible University, South Korea
[c] Institute of Computer Science & Information Engineering, National Ilan University, I-Lan, Taiwan, ROC
[d] Department of Electronic Engineering, National Ilan University, I-Lan, Taiwan, ROC
[e] Department of Electrical Engineering, National Dong Hwa University, Hualien, Taiwan, ROC

ARTICLE INFO

*Article history:*
Received 2 June 2010
Received in revised form 24 September 2010
Accepted 26 September 2010
Available online 2 October 2010

*Keywords:*
Cognitive radio
Cross-layer
Spectrum mobility
Handover
LTE networks

ABSTRACT

Cognitive radio technique is the next step toward efficient wireless bandwidth utilization. While some of the spectrum bands (unlicensed band) have been increasingly used, most of the other spectrum resources (licensed band) are underutilized. This drives the challenges of open spectrum and dynamic spectrum access concepts, which allows unlicensed users (or called secondary users, SUs) equipped with cognitive radios to opportunistically access the spectrum not used by licensed users (or called primary users, PUs). Most existing results mainly focus on designing the lower-layer cognitive radio problems. In the literature, this is the first result to investigate the higher-layer solution for cognitive radio networks. In this paper, we present a cross-layer protocol of spectrum mobility (layer-2) and handover (layer-3) in cognitive LTE networks. With the consideration of the Poisson distribution model of spectrum resources, a cross-layer handoff protocol with the minimum expected transmission time is developed in cognitive LTE networks. Performance analysis of the proposed handoff protocol is investigated. Finally, simulation results illustrates the proposed handoff protocol significantly reduces the expected transmission time and the spectrum mobility ratio.



## 1. Introduction

Over the past years, traditional approaches to spectrum management have been challenged by new insights into actual use of spectrum. Due to the wireless network bandwidth, constraints cannot fully take advantage of all of the radio spectrum resources for mobile devices and power supply cannot continue to use, and the free and unutilized radio spectrum resources are very frequent to lead the low utilization of the radio spectrum. According to Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85% [11,17]. In order to improve the utilization of the overall radio spectrum, the cognitive radio (CR) network is a useful solution to this low utilization of the radio spectrum.

The cognitive radio (CR) concept is first presented by Mitola and Maguire [21]. In CR networks, there are two types of users; one is licensed users (primary users or PUs), and the another is unlicensed users (secondary user or SUs). PUs can access the wireless network resources anytime and anywhere. SUs equipped with cognitive radios to opportunistically

* Corresponding author. Tel.: +886 2 2674 8189 x 67072; fax: +886 2 2674 4448.
*E-mail address:* yschen@mail.ntpu.edu.tw (Y.-S. Chen).

1569-190X/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.simpat.2010.09.007

access the spectrum not used by PUs. When a PU reclaims the radio spectrum resources, the SU detects the reclamation and immediately moves away the current radio spectrum resources and switch to idle radio spectrum resources. To perform above operations of PUs and SUs in CR networks, the spectrum sensing, the spectrum management, the spectrum sharing, and the spectrum mobility are four important functions. Spectrum sensing is the first important issue to find an idle radio spectrum and detect the appearance of PUs. In the literatures [9,19,20,23,26], the spectrum sensing technology can effectively and rapidly sensing the spectrum holes.

With the development of wireless network technology, the wireless mobile access has been progressed by second-generation (2G) and third-generation (3G) cellular systems. In recent years, the Third Generation Partnership Project (3GPP) has proposed a 3G long-term evolution (LTE) [1,6] toward 4G cellular systems. LTE is based on the universal terrestrial radio access (UTRA) and high-speed down-link packet access (HSDPA) and further strengthen its communications capacity to upload in order to enhance its quality of service. LTE has to coexist with 2G/3G systems, WLAN, WiMAX, etc. The handover protocols are very important for the mobile networks [10,18,22].

Recently, Software Defined Radio (SDR) is a revolutionary technology [13,14,25] to implement the CR networks. The SDR is the first development to integrate different communication capabilities. To upgrade the inconvenience and inflexibility of hardware architecture, a SDR with the programmable and reconfigurable modules is integrated with different communication protocols. A mobile terminal (SU) with SDR device uses the sensing device in the physical layer to periodically sense the current signal strength and the idle spectrum resources. With the sensed information, the SU dynamically selects a suitable spectrum hole for the spectrum mobility.

Most existing results mainly focus on designing the lower-layer cognitive radio problems. The main contribution of this paper is the first investigation of the higher-layer cognitive radio problem. In this paper, we present a cross-layer protocol of spectrum mobility (layer-2) and handover (layer-3) in cognitive LTE networks. With the consideration of the Poisson distribution of spectrum resources, we develop a cross-layer handoff protocol with the minimum expected transmission time in cognitive LTE networks. Simulation results illustrate that the proposed handoff protocol significantly reduces the expected transmission time and the spectrum mobility ratio.

The remainder of this paper is organized as follows. In Section 2, related works are described. Section 3 overviews the system architecture and the basic ideas of the proposed schemes. Section 4 describes the proposed hybrid spectrum mobility and handover protocol. Performance analysis and simulation result are presented in Sections 5 and 6. Section 7 concludes this paper.

## 2. Related works

In the literature [7,15,16,20,26], most existing results focus on designing the lower-layer (layer-1 or layer-2) cognitive radio problems.

First, the spectrum sensing is the main layer-1 task of CR system to obtain the spectrum usage information and existence information of PUs. The traditional spectrum sensing is measured by the spectral content and the radio frequency energy. In the CR, the spectrum sensing is measured under more spectrum characteristics, such as the space, time, frequency, and modulation code to determine which spectrum resource is occupied. Mishra et al. [20] proposed a spectrum sensing method based on the framework of opportunistic spectrum access networks (OSAN) to search for the available spectrum. In the OSAN framework, it divides these nodes into different clusters, each OSAN node sends the sensing information to the cluster header in the spectrum sensing cycle. Each cluster header keeps the spectrum information and the licensed user (LU) occupied channel information. The information is exchanged between cluster headers and then be forwarded to all OSAN nodes to make the accurate decision of the channel allocation. Yucek and Arslan [26] then proposed a partial match-filtering method to have a priory information about the transmission properties of feasible PUs. To having the robust spectrum sensing results, the spectrum sensing algorithm finds the available spectrum for the data transmission by detecting the presence of PUs.

Second, the dynamic spectrum allocation (DSA) is the main layer-2 task of CR system to exploit the temporal and spatial traffic statistics to allocate the underutilized spectrum to SUs. Jo and Cho [16] proposed a spectrum matching algorithms to efficiently allocate spectrum holes to SUs in the CR architecture. To minimize the probability of spectrum mobility, the spectrum matching algorithm is executed based on the different sizes of the underutilized spectrum holes and the different holding times, while the holding time is the predicted holding time for a specific spectrum hole. The spectrum matching algorithm selects and assigns a spectrum hole that is most closed to the real-spectrum holding time. Akbar and Tranter [7] recently proposed a Markov-based channel prediction algorithm (MCPA), where the channel occupancy of PUs is assumed by Poisson distribution. This algorithm utilizes the hidden Markov model (MHH) to predict the appearance of spectrum holes in different spectrum bands. In addition, Hoyhtya et al. [15] proposed a simple classification and learning of predictive channel selection method. To choose a channel with the largest idle time, this predictive channel selection method is performed based on the statistics of spectrum sensing results and the channel history. The objective of the paper is to provide insights into the higher-layer cognitive radio problem while most existing results mainly focus on designing the lower-layer cognitive radio problems.

Efforts will be made in this work to develop a higher layer cognitive radio problem. In this paper, we present a cross-layer protocol of spectrum mobility (layer-2) and handover (layer-3) in cognitive LTE networks.