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Improving spectrum handoff utilization for prioritized cognitive radio users by exploiting channel bonding with starvation mitigation

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ABSTRACT

In this study, priority based non-preemptive M/G/1 queueing model of spectrum handoff scheme is proposed in Wireless Cognitive Radio Networks. Channel bonding mechanism with starvation mitigation is employed in order to improve spectrum handoff utilization for secondary users. Since spectrum handoff offers an opportunity to secondary users for continuing their communication, it is of critical significance to determine action of primary users. In the queueing model, prioritized data traffic with aging solution to starvation is exploited to meet requirements of the secondary users. In aging mechanism; when the packet of the low priority secondary user waits in the queue more than three frame times, priority of that packet is increased. Packets of secondary users are categorized into three different priority classes, i.e., urgent, real time, and non-real time where non-real time data packets have the lowest priority while urgent data packets have the highest priority. Channel bonding mechanism is described as combining two subsequent time slots if the size of the packet is bigger than one time slot. Idle time slots for channel bonding are determined using both proactive and reactive decision based spectrum handoff schemes. Before starting spectrum handoff process with proactive scheme, first of two subsequent time slot is sensed using reactive scheme. Riverbed Modeler simulation software is utilized to simulate channel bonding and aging mechanisms. Analytical results are shown to be matched with the simulation results obtained under different load and arrival rates. This study has also exposed that the throughput of secondary users could be increased significantly by employing aging solution to starvation, and channel bonding mechanisms.

1. Introduction

Cognitive radio is a new technology that enhances spectrum usage by means of distinctive sensing mechanism [1–4]. Cognitive radio changes parameters by interacting with the environment [5–7]. With the help of spectrum sensing technique, secondary users discover underutilized spectrum holes, and utilize these spectrum holes without causing any interference to the licensed primary users [8–11]. When an action of primary users is detected in licensed channels, secondary users cease their transmissions or find a new channel to carry on their communications [12,13]. Continuing a transmission in a new channel for secondary users in order not to cause any harmful interference to the primary users is described as spectrum handoff process [14,15]. In spectrum handoff scheme, secondary users alter their transmission channel with reactive decision based scheme or proactive decision based scheme [14,16]. In reactive decision based spectrum handoff, secondary users search for a new channel in an on-demand way with spectrum sensing technique in order to resume the transmission after spectrum handoff demand is made [17,18]. In proactive decision based spectrum handoff, spectrum handoff channels are prepared before the start of the transmission for future spectrum handoffs by taking long term observations into consideration [11,19]. Reactive decision based spectrum handoff increases number of handoff while proactive decision based spectrum handoff avoids spectrum sensing time [12,20].

There are numerous research articles about spectrum handoff, channel bonding, and starvation mitigation in recent times [21,22]. Shiang and Schaar investigate dynamic channel selection strategy for independent wireless users [1]. In order to manage available spectrum resources, information interchange among users is essential in their strategy. However, priority classes are not considered in their research. Zahed et al. proposed a prioritized proactive spectrum handoff decision technique to decrease total service time [2]. In their study, preemptive resume priority M/M/1 queue is used, but number of handoff parameter is not

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taken into account. Chu et al. investigated priority traffic based dynamic spectrum access for cognitive radio networks utilizing multi-dimensional Markov chain [11]. In their work, blocking probability and dropping probability is evaluated, but cumulative number of handoff is not taken into account. Joshi et al. proposed analytical framework that investigates channel throughput at the medium access layer for opportunistic networks with channel bonding [23]. In their work, network size and the total number of available channels are investigated thoroughly while delay is not evaluated. Zhang et al. investigated a Markov transition model integrated with the preemptive resume priority M/M/2 queueing network [12]. Cumulative handoff delay is evaluated comprehensively in their study, but cumulative number of handoff is not evaluated. Wang and Wang propose the spectrum handoff mechanisms for cognitive radio networks [13]. Reactive sensing based spectrum handoff and proactive decision based spectrum handoff are comparatively studied while repetitive spectrum handoff problem are not evaluated in their paper. Lertsinsrubtavee et al. propose a new spectrum handoff mechanism that aims to reduce redundant spectrum handoff processes [14]. In their research, backup channels are utilized to avoid repeated spectrum handoffs while priority is not taken into account. Kai and Liew developed the trap theory to analyze temporal throughput fluctuations and to compute degrees of starvation for CSMA (Carrier Sense Multiple Access) based wireless networks [24]. In their work, analytical model and throughput are comprehensively studied while delay parameter is not taken into account. Arif et al. investigate probability of spectrum handoff under different traffic models for secondary users [15]. In their work, different distribution models are simulated in order to validate theoretical results while priority classes are not evaluated. Yang et al. propose optimal frequency selection scheme for secondary users [16]. In their work, optimal frequency is acquired considering tradeoff between interference probability and successful transmission probability while successive spectrum handoff is disregarded. Lee and Yeo analyze spectrum handoff delay and channel availability for secondary users [17]. In their work, priority classes are ignored while effects of spectrum sensing time, data transmission time and state transition of primary users are comparatively evaluated.

In this study, priority based non-preemptive M/G/1 queueing model of spectrum handoff process is proposed. Channel bonding mechanism with starvation mitigation is utilized to increase spectrum handoff utilization for secondary users. Because spectrum handoff offers an opportunity to secondary users for keeping on their transmission, it is of crucial importance to determine action of primary users. In the queueing model, prioritized data traffic with aging solution to starvation is utilized to meet requirements of the secondary users. In aging mechanism; when the packet of the low priority secondary user waits in the queue more than three frame times, priority of that packet is increased. Packets of secondary users are categorized into three different priority classes, i.e., urgent, real time, and non-real time where non-real time data packets have the lowest priority while urgent data packets have the highest priority. Channel bonding mechanism is described as combining two succeeding time slots if the size of the packet is bigger than one time slot. Idle time slots for channel bonding are determined using both proactive and reactive decision based spectrum handoff technique. Before starting spectrum handoff process with proactive scheme, first of two succeeding time slot is sensed using reactive scheme. For our network model, a cognitive wireless network that composes of primary users, secondary users, and base stations is designed. Having license for their communications, primary users use their time slots at any time exploiting TDMA (Time Division Multiple Access) as medium access control protocol. Secondary users communicate through the base station utilizing slotted Aloha as a medium access technique only when time slots are idle. Riverbed Modeler simulation software is exploited to simulate channel bonding and aging mechanisms. Analytical results are seen to be matched with the simulation results obtained under different load and arrival rates. This study has also revealed that the throughput of secondary users could be enhanced significantly by utilizing aging solution to starvation, and channel bonding mechanisms.

Main contributions of our research are as follows: (i) priority classes, namely, urgent, real time, non-real time are taken into account, (ii) aging solution to starvation is employed for low priority secondary users, (iii) cumulative handoff delay, blocking probability, forced termination probability, and throughput are evaluated, (iv) analytical results obtained from Matlab software are validated with the simulation results obtained from Riverbed software, and (v) to the best of authors knowledge, throughput of secondary users is improved by utilizing spectrum handoff with channel bonding mechanism for the first time in the literature.

2. Spectrum handoff management

Cognitive radio is a technology that allows secondary users to exploit spectrum holes in an opportunistic way [3,9,21]. Secondary users are usually considered as guests to the spectrum due to having no license [2,17]. Therefore, when some parts of the spectrum exploited by secondary user are demanded by primary users, the transmission of secondary user needs to be either terminated or continued in other available parts of the spectrum. The concept of carrying on a transmission in other portions of the spectrum is described as spectrum handoff [25,26]. Mostly, there are three different conditions that spectrum handoff occurs: when action of primary user is detected on the licensed spectrum, when secondary user fails the connection because of the mobility, or when available spectrum cannot support requirements [10,13,20].

In Fig. 1, classification of spectrum handoff schemes is- demonstrated. Spectrum handoff process in cognitive radio networks is mainly consisting of switching handoff and non-switching handoff. Moreover, switching handoff technique is split into reactive decision based scheme and proactive decision based scheme in the literature [27,28].

2.1. Spectrum handoff process based on reactive decision scheme

In reactive decision based spectrum handoff, secondary users employ spectrum handoff process after discovering communication lost [11]. This method requires immediate spectrum handoff decision based on instant spectrum sensing mechanism, and causes remarkable handoff delay for secondary networks [22]. Reactive spectrum handoff is commonly used in the instant

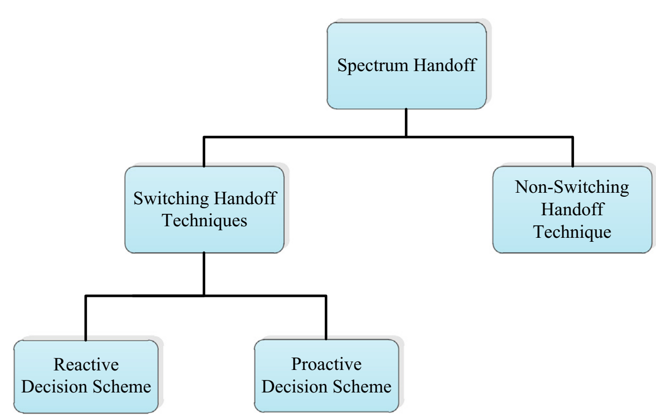

Fig. 1. Spectrum handoff schemes.