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Impact of residual time distributions of spectrum holes on spectrum handoff performance with finite switching delay in cognitive radio networks

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ABSTRACT

Cognitive radio technology ascends as a mean to improve the overall spectrum efficiency by exploring the spectrum opportunity and sharing the available channels with secondary users or cognitive users without causing harmful interference to either of the networks. Spectrum handoff is appeared to be a key strategy in order to ensure the required QoS of the primary user network and increase the overall performance of Cognitive Radio Network (CRN). In this paper, we investigate the effect of finite handoff or switching delay on the performance of spectrum mobility in a cognitive radio network. We establish an analytical model for the probability of spectrum handoff and develop an analytical formula of average spectrum handoff of a cognitive user for general residual time distributions of spectrum holes considering finite switching delay. The impact of switching delay and residual time distributions of spectrum holes on performance measuring metrics are investigated. This paper also presents a detailed comparison of results between the proposed time relationship model of spectrum handoff with and without finite switching delay in cognitive radio networks. A close proximity of the simulation result with the analytical one validates the accuracy of the proposed model.

1. Introduction

The growing diversity and wireless applications have caused congestion of the apportioned spectrum bands, which leads to user dissatisfaction. The perceptible solution is dynamic spectrum allocation and access (DSA) technology based on cognitive radio as an alternative of static spectrum allocation and access [1,2]. Cognitive radio (CR) is a smart maneuver that nous it's surrounding and has the ability to transform dynamically the radio operating parameters like operating frequency, networking, waveform, etc. to maximize the system performance [3–5]. Spectrum sensing has got significant attention over the last decade and appears to be developed for CR applications with certain limitations. However, *spectrum mobility* which is considered to be a significant component of the overall system implementation of CR network hasn't got enough attention for reason unknown.

Spectrum mobility is a task related to the change of operating frequency band of cognitive users (CUs) to maintain uninterrupted ongoing communication. When a primary user (PU) appears to engage its licensed radio channel, which is currently being used by a CU, the CU should switch to another idle spectrum band available within a certain time period to ensure *QoS* of either of the network [6]. The process of this change in the channel of operating frequency band is referred to as *spectrum handoff* [7,8]. The spectrum handoff for secondary network largely depends on PU and CU activity models. Hence, the probabilistic analysis of spectrum handoff considering both PU and CU dynamics is essential for evaluation of CR network performance.

The call duration and channel holding time of CU play a key role in the analysis of spectrum handoff performance of a CR network. The availability of channels for CU depends on the mobility of spectrum hole (i.e. arrival of primary user), which can be characterized by residual time of spectrum holes, the time that a CU continues its transmission in a spectrum hole. Traditionally, residual time and call holding time in a cellular network, are fundamentally assumed to be exponentially distributed [9]. However, field trials in [10] demonstrate that the residual time of cellular network is no longer exponential distribution. In [11,12], authors reported that the Erlang and lognormal distributions are better estimates for channel holding time than the exponential distribution in mobile environment. Fang et al. [13] derived a mathematical model for call performance parameters in personal communications services (PCS) network under exponential, Erlang-m and joint Erlang distributions of cell residence time. In [14], the authors analyzed the steady state of spectrum handoff delay considering PU signal dynamics in CR networks. Mathonsi et al. [15] designed an Enhanced Handoff (EH) algorithm for carrying network

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access in order to reduce handoff delay in heterogeneous wireless networks. An interruption-based priority queuing model is proposed in [16] to evaluate the latency performance of the system. Bayrakdar et al. presented a priority based queuing model of spectrum handoff schemes to improve spectrum handoff utilization in a CR network [17]. Particle swarm optimization is applied in [18] to minimize the spectrum handoff delay to the optimal value. In [19], the authors presented sensing based spectrum handoff process to increase the bandwidth demand in the network systems. Gkionis et al. designed a hybrid spectrum handoff scheme based on traffic patterns of the PUs in the network [20]. A survey on several channel quality estimation metrics is presented in [21], based on which the best channel for the transmission of CU is selected during spectrum handoff process. In [22,23], Li et al. proposed some novel least mean square (LMS) based algorithms to improve convergence speed and channel estimation error when the channel is sparse. In CR networks, Liu et al. [24,25] presented the concept of spectrum handoff and derived the probability of spectrum handoff when the CU service time and residual time of spectrum holes follow the exponential distribution. In [26,27], authors analyzed the performance of handoff probability for the general distribution of residual time of spectrum holes without considering handoff or switching delay in CR network. In [28], authors presented the impact of CU's service time distribution on spectrum handoff performance parameter in CR networks. However, the assumption of continuous availability of spectrum without any handoff or switching delay appears to be over simplification of the real scenario. In literature, the impact of switching or handoff delay on the probability of spectrum handoff and average spectrum handoffs are not investigated comprehensively in the domain of CR networks.

Due to stochastic behaviour of PU activity, it is difficult to achieve seamless channel transition of CUs and hence performance is degraded. *Switching delay* will arise when the interrupted CU switches its ongoing transmission from operating channel to any available channel [29] or joins the CU's queue till PU finishes its transmission [30]. Fig. 1a shows the switching handoff process of a CU between two channels. As shown in Fig. 1a, the CU begins its service by operating on channel 1 in the absence of PUs. Upon arrival of PU1 to that channel, the CU handovers that channel to PU1 immediately and performs spectrum handoff to available channel 2. During spectrum handoff process, the CU requires to perform spectrum sensing for target channel and handoff action. The delay arises during this process is known as switching or handoff delays (HD1 and HD2), which is a combination of sensing delay and transmission delay in a successful handoff process as shown in Fig. 1b. Now the CU can continue its ongoing service through the channel 2 and upon interruption in that channel, it can switch to channel 1 if available and resume its unfinished service as shown in Fig. 1a.

In this article, we present an analytical model for spectrum handoff to investigate the characteristics of performance metrics in CR network taking into account finite *handoff or switching delay* (t_s). Our main contributions to this article are summarized as follows:

- We model the probability of spectrum handoff for a CU with average finite switching delay under general residual time distributions of spectrum holes in CR networks. We assume an average finite switching delay within which a CU selects available spectrum holes to continue its ongoing transmission.
- Average spectrum handoff is an important performance metric of spectrum handoff which characterizes the traffic of a CR network. An analytical formula of average spectrum handoff is developed for complete service duration of a CU along with finite switching delay and PUs activity model.
- We present the impact of switching delay and residual time distributions of spectrum holes on spectrum handoff performance metrics. In this analysis, exponential, Erlang-m, Erlang-m, n, and lognormal distribution models for residual time of spectrum holes are considered: this is motivated by the most widely used distribution models in tele-traffic analysis [10–13]. The performance measuring metrics derived from the distribution models in presence of switching delay are compared with those in absence of switching delay.
- We also perform simulation of the probability of spectrum handoff under CR environment with and without finite switching delay for general distributions of residual time of spectrum holes to validate the proposed model.

The time relationship model of CUs for spectrum handoff with finite switching delay is established in Section 2. The theoretical analysis of this established model is presented in this section. The results obtained from both the analytical and simulation models are presented in Section 3. Section 4 concludes the paper including future work directions.

2. System model and analysis

The timing diagram of a CU call duration and residual times of spectrum holes is shown in Fig. 2. For effective analysis of spectrum handoff, some basic assumptions are to be made. Let, T_c represent the complete call duration of a CU and is exponentially distributed with average value, $1/\mu$.

It is assumed that through the proper sensing and decision rule, *fusion center* or *CR controller* organizes the spectrum holes for accessing by a CU. Let t_i (where $i = 1, 2, \ldots$) represent the *residual time* of spectrum hole #i, which is a continuous random variable having independent and identical distribution with average value, $(1/\lambda)$. The probability density function (*pdf*) of *residual time* of spectrum holes is denoted by $f_r(x)$ with parameter λ. Here t_{si} represents switching delay when a CU transfers its ongoing communication from spectrum holes #i to spectrum holes #(i + 1). For the sake of analytical tractability, CU's call duration (T_c) and switching delay (t_{si}) are considered as exponentially distributed (with *pdf* $f_c(x)$ *and* $f_t(x)$) with parameter μ and η, respectively.

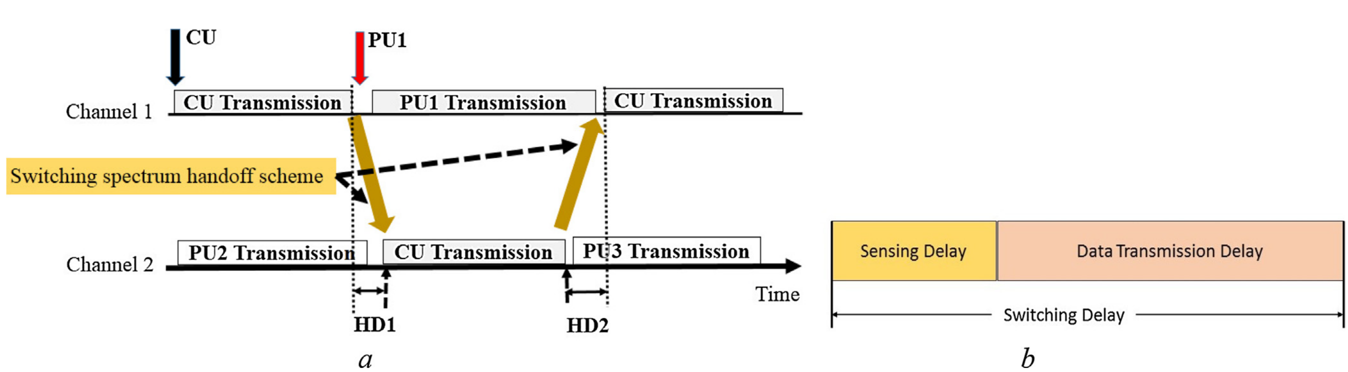

Fig. 1. (a) Switching spectrum handoff process and (b) frame structure of switching delay.