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COGNITIVE RADIO SPECTRUM ACCESS WITH CHANNEL PARTITIONING FOR SECONDARY HANDOVER CALLS†

YUTAE LEE

ABSTRACT. A dynamic spectrum access scheme with channel partitioning for secondary handover calls in cognitive radio networks is proposed to reduce forced termination probability due to spectrum handover failure. A continuous-time Markov chain method for evaluating its performance such as blocking probability, forced termination probability, and throughput is presented. Numerical and simulation results are provided to demonstrate the effectiveness of the proposed scheme with channel partitioning.

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1. Introduction

Extensive measurements of spectrum occupancy reveal that a considerable region of the licensed radio spectrum remains unused across both space and time [1]. As a solution for such inefficient spectrum usage, dynamic spectrum access (DSA) technology has been intensively studied [5]. The basic idea is to allow secondary users that do not have a licence to use the spectrum to opportunistically occupy an idle spectrum band owned by licensed users that are termed the primary users [6]. If an ongoing secondary call is preempted by a primary call, it attempts a spectrum handover to another channel. The opportunistic usage of spectrum may cause frequent spectrum handovers. If there are no available channels for a preempted call, the call is terminated forcibly. Such unpredictable forced terminations may severely degrade the performance of secondary calls. Generally speaking, the forced termination of ongoing calls is more annoying than the blocking of new calls.

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Various methods to reduce the forced termination probability have been widely studied in the existing literature. Recently, Chung et al. [2] and Kim et al. [4] proposed a channel allocation mechanism for cognitive radio networks in order to maximize throughput and minimize forced termination probability for secondary users that are not capable of spectrum handover. For cognitive networks with spectrum handover, Zhu et al. [12], Wang et al. [10], and Liu et al. [7] suggested channel reservation method for secondary handover calls to reduce the forced termination probability. Jiao et al. [3] introduced the use of backup channels for secondary calls. Wang et al. [9] considered a cognitive radio network in which secondary calls are prioritized into two priority classes, and introduced a channel reservation method for high priority secondary calls.

To reduce the forced termination probability without using additional resources such as reserved [12, 10, 7, 9] or backup [3] channels, in this paper, we propose a DSA scheme with channel partitioning for secondary handover calls. In the scheme, if an ongoing secondary call preempted by a primary call finds no idle channels, then the preempted call can handover to one of the channels already being occupied by other secondary calls. In this case the channel is occupied by multiple secondary calls simultaneously. In this paper we develop an analytical model to derive the performance measures such as blocking probability, forced termination probability, and throughput of secondary calls.

The rest of this paper is structured as follows. In Section 2, we present system model and channel partitioning policy for secondary handover calls. In Section 3, we derive the performance measures such as blocking probability, forced termination probability, and throughput of secondary calls. Numerical examples are provided in Section 4 and finally Section 5 concludes this paper.

2. System model

A cognitive radio network with multiple channels is considered. A channel can be assigned to one primary call or up to M secondary calls. The channels assigned to primary calls are called 'primary channel', and those assigned to secondary calls 'secondary channel'. The data transmission rate of each call on a secondary channel is in inverse proportion to the number of calls on the channel.

In cognitive radio networks, primary users have exclusive privilege to access the channels, and the activities of primary users are not affected by those of secondary users. An incoming primary call is blocked if all the channels are occupied by primary calls. Otherwise, the incoming call is assigned a channel randomly with equal probability among the channels which are not occupied by other primary calls. Thus, the incoming call may claim a secondary channel even though there are some idle channels.

Secondary call transmissions can be effectively managed by DSA scheme, whose objective is to assign appropriate channels to new and handover secondary calls. Assuming there is a central controller [11], we propose a DSA

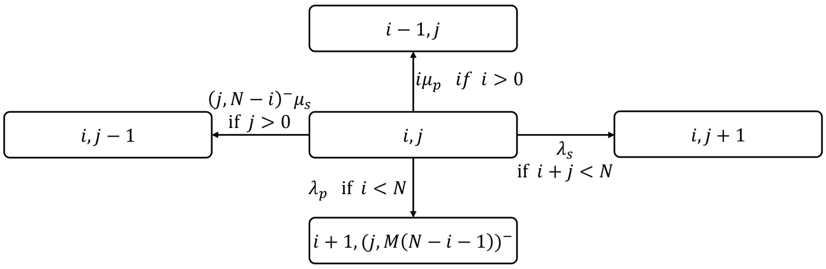

FIGURE 1. State transition from state (i, j).

scheme as follows. An incoming secondary call is assigned a channel randomly with equal probability among the idle channels, if any. Otherwise, if all channels are occupied by primary or secondary calls, the incoming call is blocked–even though multiple ongoing secondary calls can be assigned one channel–in order not to degrade the performance of ongoing secondary calls. When an incoming primary call claims a secondary channel, the secondary calls on the channel are preempted immediately. Every preempted call attempts a spectrum handover to one of the available channels, each of which is idle or occupied by only secondary calls less than M. During handover, the available channels are assigned in ascending order of the number of secondary calls occupying them. If the available channels are not enough to accommodate all the preempted calls, some of the calls will be terminated forcibly. When a primary or secondary call completes its transmission over a channel, say channel a, an ongoing secondary call on one of the most crowded channels attempts a spectrum handover to channel a until the difference between the number of calls on one of the most crowded channels and that of channel a is not more than 1.

3. Analysis

An analytical model for the cognitive radio network with the proposed DSA scheme is developed using continuous-time Markov chain. We consider a cognitive network with N channels available for transmission by primary and secondary users. The arrivals of primary and secondary calls independently follow Poisson processes with rates λ_p and λ_s, respectively. The transmission rate of each primary call is μ_p. When a secondary channel is allocated to m secondary calls, the transmission rate for each of the calls is assumed to be μ_s/m.

Let $p(t)$ and $s(t)$ be the stochastic processes representing the number of ongoing primary and secondary calls in the system, respectively, at time t. The bidimensional process $\{(p(t), s(t))\}$ is a continuous-time Markov chain with state space $\{(i, j) \mid 0 \le i \le N,\ 0 \le j \le (M(N-i), N)^-\}$, where $(a, b)^-$ denotes the minimum of a and b. The only non-null transition rates $q_{(i,j),(k,l)}$'s from state

(i, j) to state (k, l) for the Markov chain are obtained as follows:

$$q_{(i,j),(i-1,j)} = i\mu_p, \quad i > 0, \tag{1}$$

$$q_{(i,j),(i,j-1)} = (j, N-i)^{-}\mu_s, \quad j > 0, \tag{2}$$

$$q_{(i,j),(i,j+1)} = \lambda_s, \quad i+j < N, \tag{3}$$

$$q_{(i,j),(i+1,(j,M(N-i-1))^{-})} = \lambda_p, \quad i < N, \tag{4}$$

for $0 \le i \le N$ and $0 \le j \le (M(N-i), N)^{-}$. These transition rates account, respectively, for: 1) the service completion of a primary call; 2) the service completion of a secondary call; 3) the arrival of a secondary call; and 4) the arrival of a primary call (See Figure1).

Let

$$\pi_{i,j} \equiv \lim_{t\to\infty} \mathrm{P}\{p(t) = i, s(t) = j\} \tag{5}$$

be the stationary probability distribution of the Markov chain $\{(p(t), s(t))\}$. The distribution $\{\pi_{i,j}\}$ is easily obtained by finding the corresponding state transition rate matrix and applying the Gauss-Seidel method [8]. The performance measures for secondary calls are expressed using the stationary distribution $\{\pi_{i,j}\}$ of the continuous-time Markov chain. We derive performance measures such as blocking probability, forced termination probability, and throughput of secondary calls.

The blocking probability is defined as the probability that an arriving secondary call is not permitted to access channels and is blocked. An arriving secondary call is blocked if there are no idle channels. Thus, the blocking probability of secondary calls, denoted as P_B, is expressed as

$$P_B = \sum_{i=0}^{N} \sum_{j=N-i}^{(M(N-i),N)^{-}} \pi_{i,j}. \tag{6}$$

The forced termination probability is defined as the probability that an ongoing secondary call is preempted by an incoming primary call and its spectrum handover fails. The forced termination probability, denoted as P_D, is expressed as follows:

$$P_D = \frac{\sum_{i=0}^{N-1} \sum_{j=(M(N-i-1),N)^{-}+1}^{(M(N-i),N)^{-}} \pi_{i,j}[j-(M(N-i-1),N)^{-}]\lambda_p}{\lambda_s(1-P_B)}.$$

We are in the condition to determine the throughput defined as the mean number of successfully transmitted calls per unit time. Let ρ denote the throughput for secondary calls, which is given by

$$\rho = \lambda_s(1-P_B)(1-P_D). \tag{7}$$

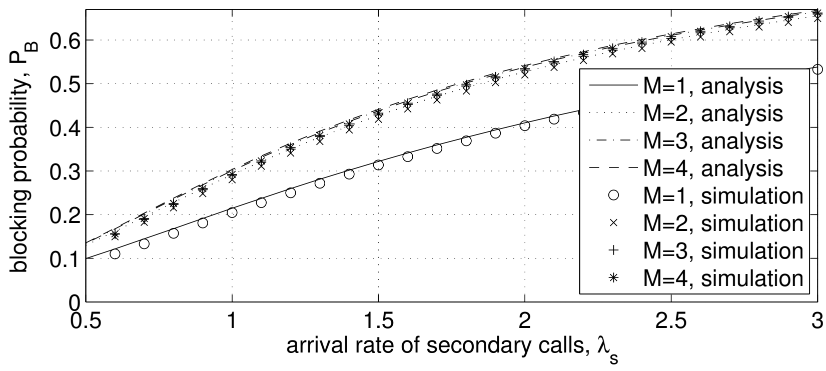

FIGURE 2. Blocking probability of secondary calls.

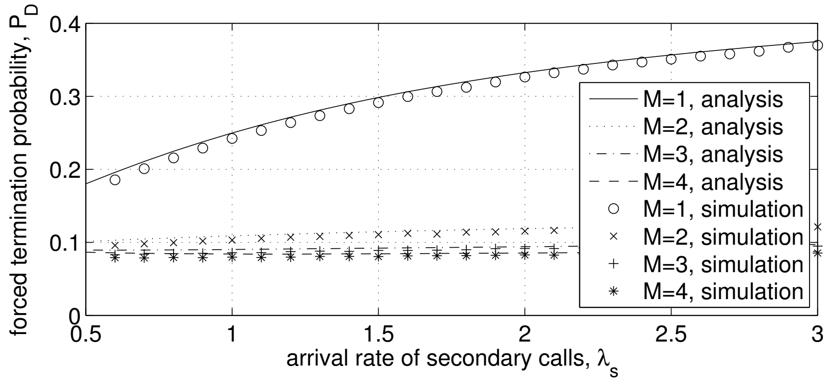

FIGURE 3. Forced termination probability of secondary calls.

4. Numerical examples

Numerical results are obtained for the blocking probability, forced termination probability, and throughput for secondary calls. The accuracy of the analytical model is verified through simulations. The parameters used in our experiment are as follows: $N = 10$, $M = 1, 2, 3, 4$, $\lambda_p = 1.0$, $0.5 \leq \lambda_s \leq 3.0$, $\mu_p = 0.2$, and $\mu_s = 0.2$. These parameters are solely for illustration purposes and can be modified to reflect other situations.

Figure 2 and Figure 3 show the blocking and forced termination probabilities, respectively, of secondary calls as function of the arrival rate λ_s for various M's. It can be seen that, as the value M increases, the forced termination probabilities decrease at the cost of increasing blocking probabilities. This is because the number of successful handovers for preempted calls increases with

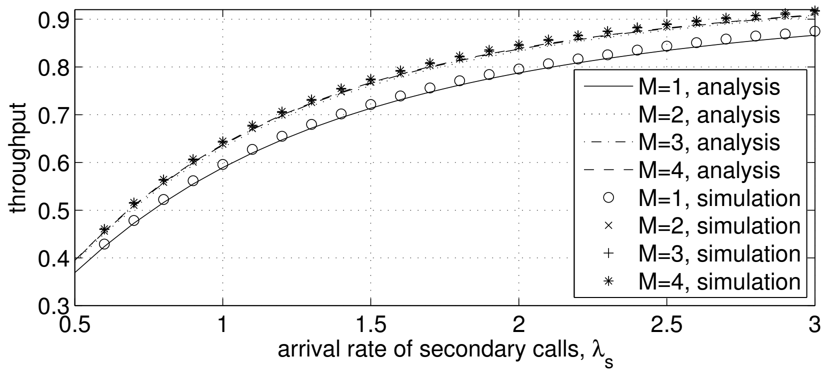

FIGURE 4. Throughput of secondary calls.

an increase in the value M, resulting in lower forced termination probabilities, less idle channels, and higher blocking probabilities of secondary calls. It is worth noting that the performance difference between the case with channel partitioning ($M > 1$) and the case without channel partitioning ($M = 1$) is noticeable, while there is a little performance difference among the cases with $M = 2$, 3, and 4. As expected, the blocking and forced termination probabilities increase as λ_s increases. Figure 2 and Figure 3 also show that the analytical results match well with the simulation results.

Figure 4 shows the effect of λ_s and M on the throughput of secondary calls. It can be seen that as λ_s increases, the throughput for secondary calls also increases for $M = 1, 2, 3, 4$. Figure 4 also shows that the case with larger M gives higher throughput compared to the case with smaller M. Again, the analytical and simulation results match well.

5. Conclusion

A DSA scheme with channel partitioning for secondary handover calls was proposed to reduce forced termination probability in cognitive radio networks. In the scheme, a preempted secondary call can handover to a channel being occupied by other secondary calls, and the channel may be used by multiple secondary calls simultaneously. A continuous-time Markov chain method was presented to evaluate the performance such as blocking probability, forced termination probability, and throughput. Numerical results were also presented and compared with simulation data. At the cost of increasing blocking probability, the channel partitioning significantly decreases forced termination probability and increases throughput of secondary calls.

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Yutae Lee received B.Sc., M.Sc., and Ph.D from KAIST. Since 2001 he has been at Dongeui University. His research interests include queueing theory and performance analysis of telecommunication networks.

Department of Information and Communication Engineering, Dongeui University, Busan 614-714, Korea

e-mail: ylee@deu.ac.kr