# *Spectrum Handover Mechanism for Secondary Users in Cognitive Femtocell HetNets*

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***Abstract*—This paper proposes a reserved channel based spectrum handover mechanism for cognitive heterogeneous networks (HetNet). To properly handover secondary users from Macro to Femto base stations and maintaining an acceptable protection on the primary users, we propose a priority-based scheme in which several channels are reserved only for handover or Secondary users while the rest of the channel can be shared by the primary and the secondary users. The objective is to maximize the throughput of secondary users meanwhile the throughput of the primary users is above a predefined value. To this end, we jointly optimize the number of reserved channels and sensing time subject to constraints on false alarm and detection probability of the secondary users as well as throughput of the primary users. It is shown that the proposed optimization problem is convex and therefore can be solved efficiently by numerical methods. The simulation results show that, this method can improve the throughput of the secondary users in such a way that the achieved throughput is not sensitive to the arrival rate of the primary users. Moreover, it is found that the optimal number of reserved channels keeps the blocking probability of the primary users below an acceptable level.**

***Keywords*—HetNet; Cognitive radio; Specrum handover; femtocell; macrocell; reserved channel scheme.**

## I. INTRODUCTION

Intelligent radios which can be programmed and configured dynamically, have made cognitive engine capable of configuring radio system parameters, including the operating frequency, and waveforms [1], [2]. In view of the main functions of cognitive radio such as power control and spectrum sensing, spectrum management is the main concern [3]. The main objective of cognitive radio is capturing the best available spectrum to meet secondary users' service requirements, while not jeopardizing the primary users' service quality.

Moreover, using cognitive radio in cellular networks is an effective solution to provide good services for end users suffered from spectrum limitations. In this way, promising technologies such as cognitive Femtocell can utilize the spectrum in an efficient manner while improving the coverage area [4], [5]. However, some technical challenges such as network architecture, spectrum management, interference suppression, and handover should be first alleviated in order to fully benefit this technology.

Spectrum management is one of the main concern in individual cognitive networks and also in cognitive Femtocell network [6]. This is highly impressed by spectrum handovers in cognitive Femtocell network. Due to the presence of the primary users and the need of channel leaving by the secondary users, unnecessary spectrum handovers occur which may drastically degrade the performance of the system and also QoS of the secondary users. Changing frequency imposes a signaling overhead, increases the transmission time, and may even cause cell outage due to the difference in path loss. Therefore, link maintenance is very important for secondary users. Author in [7] introduced a scheme for seamless spectrum handover in multi-cell cognitive radio system. The procedure is done from high to low and low to high frequency to reduce both, the cell outage and the total number of handovers. To use opportunistic spectrum access, a proactive collaborative algorithm is represented in [8] to strongly detect the spectrum holes via the received signal. Another spectrum handover strategy which depends on the instantaneous sensing is reactive decision, where the secondary users need to sense each channel at the beginning of the transmission phase in order to find an idle one [9].

Resource management in WiMax cognitive radio integrated with Femtocell network has been studied in [10]. It is shown that by using multi-hop cooperative communication, the spectrum holes can be fully exploited in a feasible manner. Channel scheduling in spectrum handover is investigated in [11] that is a kind of proactive decision in cognitive radios. It suggests that the data packet can be conducted to other channels if the current channel is disabled. This is done by appropriate channel scheduling and reducing the number of disqualified channels. A traffic-adaptive spectrum handover is studied analytically in [12] which shows that it can efficiently reduce the transmission time. In [13], a new scheme is proposed which anticipates the trigger of spectrum handover and the secondary users make a decision to find the target channel. This helps to reduce the dropping rate of the secondary users. The idea of using the backup channels for cognitive ad hoc networks is addressed in [14] which avoids redundant spectrum handovers.

Most of existing works have focused on decreasing the signaling load, unnecessary spectrum handovers, and sensing time in cognitive radios. In this paper, we take a step forward and jointly consider the throughput, reserved channels, and sensing time in spectrum handover. Regarding the significant role of spectrum handover on the QoS of both the primary and secondary users, we incorporate the idea of reserved channel to improve the throughput of the secondary users in a cognitive HetNet. By optimizing the sensing time and the number of reserved channels, we will show that the throughput of the secondary users would not be affected by the arrival rate of the primary users.

The rest of the paper is organized as follows. Section II describes the proposed system mode. Then, the problem of spectrum handover and optimization approach is discussed in Section III. In Section IV, we show simulation results. Finally, Section V concludes the paper.

## II. System Model

We consider a two-tier wireless network as shown in Fig. 1, where Macro cell covers a Femto cell area. Secondary users request handover to Femto base station (BS) in a constant arrival rate of $\lambda_{HO}$ (equals to 0.15 in this research). Some primary users with different arrival rates may also present at Femtocell BS. Femtocell BS can sense the available spectrum and initialize the channel reserving list to allocate them to handover users.

We use a priority-based strategy in the proposed model, where n out of K channels are exclusively reserved for handover requests of secondary users [15]. The remaining $N = K - n$ channels are common between the primary and secondary users. If a handover request cannot find any available channel in the above mentioned channels, it would be blocked. The pertinent state transition diagram is illustrated in Fig. 2. We define the state $i$ ($i = 0, 1, \cdots, K$) of a cell as the number of calls in progress for the Femto BS of that cell. Let $P(i)$ represents the steady-state probability that the Femto BS is in state $i$. The probability $P(i)$ can be determined in the usual way for birth–death processes. Using the state balance equations in (1-a, b), the steady-state probability $P(i)$ is easily found as follows [15]:

$$i\mu P(i) = (\lambda_p + \lambda_{HO})P(i-1) \qquad 0 \le i \le N \tag{1a}$$

$$i\mu P(i) = (\lambda_{HO})P(i-1) \qquad N \le i \le K \tag{1b}$$

and

$$\sum_{i=0}^{K} P(i) = 1$$

$$P(0) = \left[\sum_{i=0}^{N} \frac{(\lambda_p+\lambda_{HO})^i}{i!\mu^i} + \sum_{i=N+1}^{K} \frac{(\lambda_p+\lambda_{HO})^N {\lambda_{HO}}^{i-N}}{i!\mu^i}\right]^{-1} \tag{2}$$

Then, the blocking probabilities for primary and handover (secondary) requests are defined as (3a) and (3b), respectively.

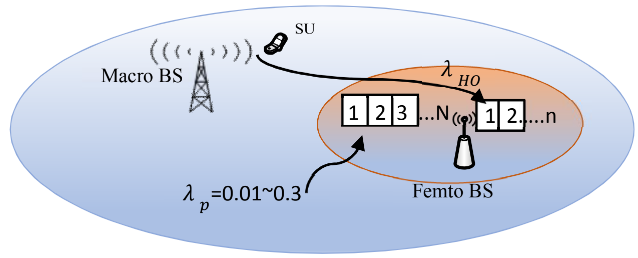


Fig. 1. System model for a two-tier HetNet and channel model for Femtocell with $K = N + n$ channels

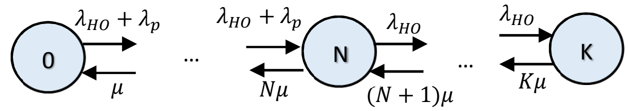


Fig. 2. State transition diagram

$$P_{block\_primay} = \sum_{i=N}^{K} P(i) \tag{3a}$$

$$P_{block\_HO} = \frac{(\lambda_p+\lambda_{HO})^N {\lambda_{HO}}^{K-N}}{K!\mu^K} P(0) \tag{3b}$$

If the handover calls cannot find any idle reserved channel, they are allowed to use the shared channels. But, if all shared channels are engaged, the call would be blocked. On the other hand, finding an idle channel among shared ones, may lead to some difficulties for the secondary users. Because it may encounter several interruptions from the primary users. In this way, due to extra interruptions, the overall service time of the secondary users will be extended and the forced termination will be increased. Consecutive sensing also affects the throughput of the secondary users.

## III. Problem Formulation

### A. Throughput of the Primary and the Secondary Users

We adopt a traditional IEEE 802.22 frame structure for our cognitive network [16]. As can be seen in Fig. 3, a fraction of the frame duration T is dedicated for spectrum sensing $t_s$; and the rest of it for data transmission. During the sensing time, the presence of the primary users would be detected. Secondary users send their data if there is no primary user. Assuming that the energy detection (ED) algorithm is used for spectrum sensing, the throughput of the secondary users can be defined as [17, 18]

$$R_{SU}(t_s) = \left(\frac{T-t_s}{T}\right)(1 - P_{false}(\gamma, t_s))C_0 P(H_0) \tag{4}$$

where $C_0 = log_2(1 + SNR_{SU})$, the probability $P(H_0)$ represents the primary users activity and $P_{false}(\gamma, t_s)$ is the false alarm probability during the sensing period and is related to the detection probability as follow [17]

$$P_{false} = Q\left(\left(\sqrt{2\gamma+1}\right)Q^{-1}(P_d) + \sqrt{t_s f_s}\gamma\right) \tag{5}$$

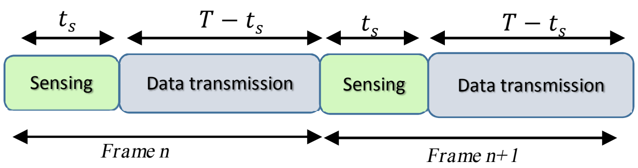


Fig. 3. Traditional frame structure for the cognitive radio network

Similarly, we can determine the throughput of the primary users but it should be noted that there is no sensing time and false alarm in this case. According to FCC rules, when the primary user ask for a channel, the secondary user must release it. Ideally, it has no delay but in the real cases this process need a short delay which may cause slight decrement on the throughput of the primary users.

We further define the normalized throughput of the primary and the secondary users per channel, $\tilde{R}_{SU}(t_s)$ and $\tilde{R}_{PU}(t_s)$ , as can be deduced from equation (6-a) and (6-b). When a secondary user selects and engages a reserved channel, there is no sensing time because these channels are private for secondary users. In contrast, a shared channel can be used by a secondary user, if the sensing process is completed and there is no active primary user in it. Thus, we have:

$$\tilde{R}_{SU}(t_s) = R_{su}(t_s = 0)\left(\frac{n}{N}\right) + R_{su}(t_s)\left(\frac{N-n}{N}\right) \qquad (6a)$$

$$\tilde{R}_{PU}(t_s) = log_2(1 + SNR_{PU})\left(\frac{N-n}{N}\right) \qquad (6b)$$

The secondary user throughput is characterized by two factors, i.e., the arrival rate and the number of interruptions due to requests of primary user. As depicted in Fig. 4, considering the sensing time of 0.015, the secondary throughput is at maximum. But increasing the arrival rate of primary users from 0.02 to 0.3, causes a reduction of throughput from 5.5 to 3.4 (bits/Sec/Hz/channel).

As mentioned before, increasing the number of primary interruptions decrease the throughput of secondary users. The simulation results shown in Fig. 5, demonstrate that higher number of interruptions causes significant reduction in throughput of secondary users. The higher the sensing time, the lower the number of tolerable interruptions is. However, it is a flat curve for primary users.

According to these limitations and tradeoffs, we introduce a useful optimization problem in the next subsection to improve the secondary user throughput while maintaining a reliable communication for primary users.

B. Optimization Problem

As the secondary (handover) users can use both reserved and shared channels, it is clear that the secondary user prefers to access more private channels to achieve the highest possible throughput. Such a selfish behavior of secondary users is not beneficial for primary users. Because the number of reserved channels may reduce the per channel throughput of the primary users. Therefore, maintaining the primary throughput above an acceptable level is necessary.

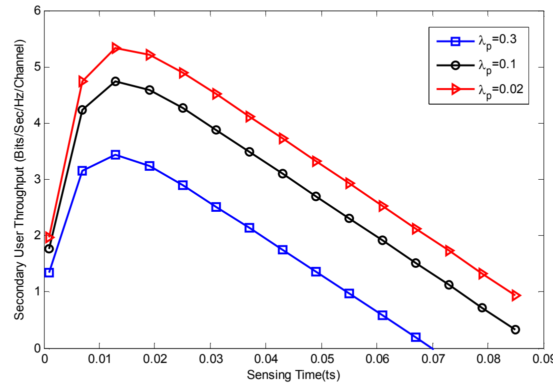


Fig. 4. Throughput of the secondary users vs sensing time at different arrival rate of the primary users

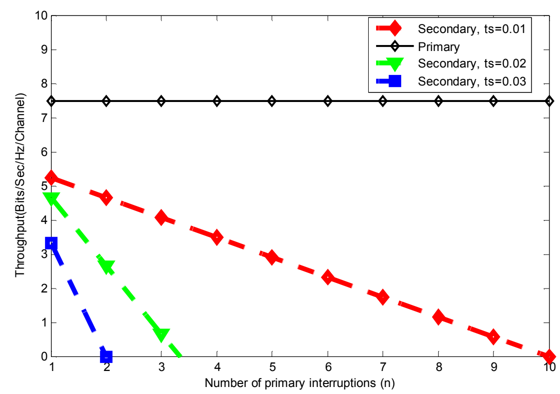


Fig. 5. Throughput of the secondary users vs the number of interruptions for different sensing times

In addition, the collision of the primary and the secondary users need to be taken into account in the sensing process. Accomplishing the sensing process with a high detection probability ($\geq 0.9$) and low false alarm ($\leq 0.1$) is a traditional treatment to prevent a collision. Increasing the sensing time in our proposed method yields higher detection probability but decreases the throughput of the secondary users. So, it is evident that there is a tradeoff between sensing time and the number of reserved channels. Exploiting the following optimization problem, one can maximize the secondary users' throughput and maintain the QoS of primary users in an acceptable level.

$$\textbf{Maximize } \tilde{R}_{SU}$$

**Subject to:**

$$P_{detection} \geq 0.9$$

$$P_{false} \leq 0.1$$

$$\tilde{R}_{PU} \geq \alpha$$

Since the objective and constraints of this problem are concave, the optimization problem can be efficiently solved by numerical methods.

## IV. SIMULATION RESULTS

In this section, we evaluate the proposed scheme in terms of the throughput of the secondary users and blocking probability of the primary users.

The simulations is based on IEEE 802.22 standard in which the channel bandwidth is 6MHz. Table I shows other simulation parameters. Fig. 6 shows the optimized average throughput of the secondary users. As can be seen in this figure, in the proposed scheme, increasing the arrival rate of the primary users does not affect the throughput of secondary users. Considering the results for always-changing spectrum handover and always staying (none-spectrum handover) algorithm which were proposed in IEEE 802.22 standard [19], it can be seen in Fig. 6 that increasing the arrival rate of the primary users causes a significant reduction in the throughput. This is because the secondary user must change its current channel by any interruption of the primary user (always changing) or wait on its current channel (always staying). In this way more time is spent for sensing process or waits for service time of the primary user. Hence, the throughput degrades.

The total throughput (including primary and secondary ones), before and after optimization, is illustrated in Fig. 7. Increasing the arrival rate of the primary users from 0.02 to 0.3 reduces the throughput form 1 to about 0.1 while using the proposed optimization method, one can keep the total throughput of the system at a fixed value for different arrival rates. Another interesting point in Fig. 7 is that after achieving the maximum value, the dependence of the system throughput to the sensing time would be eliminated. This is due to the fact that the sensing time is optimized to guarantee $P_{detection} \geq 0.9$ and this value is constant at different arrival rates of primary users. In addition, once the secondary user handover to the reserved channel there is no primary user in that channel. Hence, there is no interruption and extra delay.

The impact of the reserved channels on the blocking probability of the primary users is also examined. To retain the blocking probability lower than a predefined level, the number of shared channels should be increased especially when the arrival rate of the primary users is going to rise. Solving the proposed optimization problem yields the maximum number of reserved channels of 2, regarding the total number of channels of 10 in our case study, it is clear that 8 of them can be shared and with this shared channels the blocking of the primary users would be 0.07 at a high arrival rate of 0.3 (Fig. 8).

TABLE I

SIMULATION PARAMETERS

| Parameter | Description | Value |
|---|---|---|
| T | Frame duration | 100 ms |
| $SNR_{SU}$ | Signal to noise ratio for secondary transmitter | 10 dB |
| $SNR_{PU}$ | Signal to noise ratio for primary transmitter | 20dB |
| $\gamma$ | Threshold | -20 dB |
| $f_s$ | Sampling Frequency | 6 MHz |
| $t_{ho}$ | Handover execution time | $1\mu s$ |

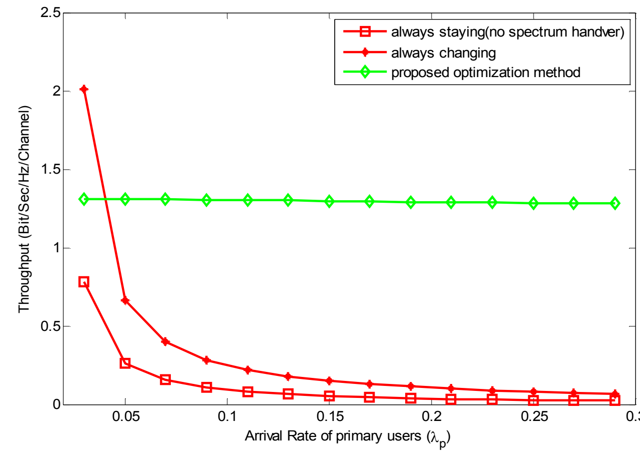


Fig. 6. Throughput of the secondary users vs arrival rate of the primary user

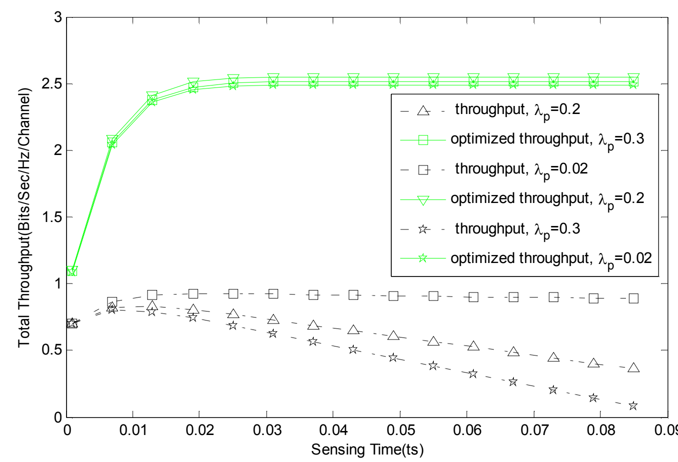


Fig. 7. Total throughput vs sensing time

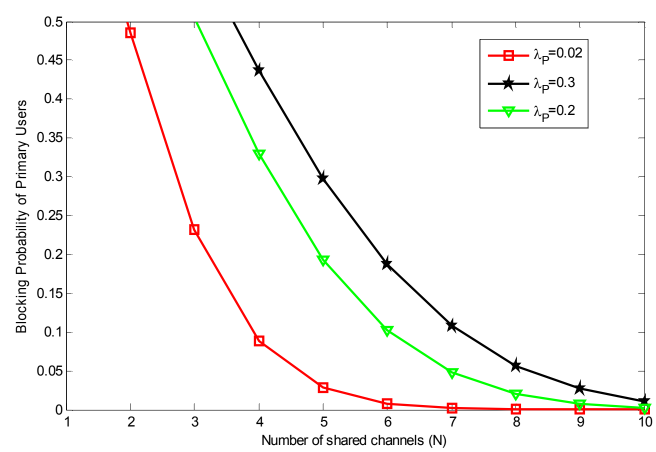


Fig. 8. Blocking probability of the primary users vs the number of shared channels

## V. CONCLUSION

In this paper, a new spectrum handover mechanism was introduced for a cognitive heterogeneous network which adopts a reserved channel-based approach. We showed that there is a tradeoff between the number of reserved channels, sensing time, and throughput of the primary and the secondary users. Solving the optimization problem and finding appropriate values of sensing time and number of reserved channels, the throughput of the secondary users can be improved by increasing the arrival rate of the primary users. In addition, the overall throughput of the network was compared with non-reserving cases and it was shown that by applying the reserving channel strategy, different arrival rates of primary users can not cause any malfunction on the network performance. Furthermore, the blocking probability of the primary users was evaluated and it was shown that with the optimum number of reserved channels, it remains lower than 0.07.

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