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A generalized order user selection scheme for cognitive networks with imperfect channel estimation and multiple primary users

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ABSTRACT

In this paper, we study the performance of multiuser cognitive networks with multiple primary users and imperfect channel estimation. Two scenarios are considered: primary users with the same spectrum band and primary users with orthogonal spectrum bands. The utilized generalized order user selection scheme is efficient in situations where a user other than the best user (user of best channel) is erroneously selected by the scheduling unit for conducting its communication as an imperfect channel estimation or an outdated channel information condition. In this scheme, the secondary user with the second or even the *N*th best signal-to-noise ratio (SNR) is assigned the system resources by a scheduler. In our paper, closed-form expressions are derived for the outage probability, average symbol error probability (ASEP), and ergodic channel capacity of the secondary system assuming imperfectly estimated Rayleigh fading channels. Furthermore, closed-form expressions are derived for the outage probability, considering the interference from a primary transmitter. Also, to get more insights about the system performance, the system is studied at the high SNR regime where the diversity order and coding gain are derived and analyzed. The achieved analytical and asymptotic results are verified by Monte-Carlo simulations. The main results illustrate that the number of primary users affects the performance of the secondary system through affecting only the coding gain and not the diversity order. Results show that in the case where the primary users use the same spectrum band, the system performance enhances as the number of primary users decreases and degrades as the number of primary users increases. In contrast, when the primary users use orthogonal spectrum bands, findings illustrate that the system performance degrades as the number of primary users decreases and enhances as the number of primary users increases. Also, results show that a zero diversity gain is achieved by the system and a noise floor appears in the results when the secondary users channels are imperfectly estimated.

1. Introduction

The multiuser diversity is achieved by taking advantage of the channel fading variations in wireless networks. More specifically, it was shown that selecting the user with the best instantaneous channel each transmitting or receiving time increases the chance of having the communication to occur over a good channel. As a way for improving the spectrum utilization efficiency in wireless networks, the cognitive radio has been proposed in [1]. In such networks, the secondary or cognitive users can share the spectrum with primary users via underlay, overlay, or interweave paradigms [2]. The overlay cognitive scheme allows secondary users to share the frequency bands of primary users only if the interference between them is zero; whereas, the underlay paradigm which is adopted in this paper allows secondary users to share the spectrum of primary users if the interference between them is below a certain threshold.

As an efficient way for selecting among users, the opportunistic scheduling was used to select among secondary users in cognitive networks with adaptive modulation in [3]. In the opportunistic scheduling, the user with the best instantaneous channel is always selected by the scheduling unit for data transmission or reception. The multiuser diversity gain and bit error rate for multiple access channels, broadcast channels, and parallel access channels in cognitive networks with opportunistic scheduling were derived in [4]. Recently, Wang

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et al. proposed in [5] a limited feedback based underlay spectrum sharing scheme, where the opportunistic scheduling was used to select among secondary users in a downlink transmission. The opportunistic scheduling was also used in [6] in selecting among secondary users in an uplink transmission. Most recently, the secondary users were allowed to utilize the spectrum of primary users in an opportunistic way in [7]. All the previous studies assumed the presence of a single primary receiver in their analysis. As an extension to previous studies, the performance of multiuser cognitive networks with opportunistic scheduling and multiple primary receivers was studied in [8–10]. All the aforementioned papers assumed perfectly estimated channels. Some interference alignment schemes for multiuser cognitive networks were recently proposed in [11,12]. In [11], two partial-IA based algorithms were proposed to design the precoding matrices of secondary users, in which the interference is aligned at the primary receiver with much lower overhead and complexity. The primary user's precoding matrix was also designed to maximize its throughput accordingly. Also, to further improve the performance of secondary users, their decoding matrices were re-designed to maximize their signal-to-interference-plus-noise ratio (SINR). Three power allocation algorithms for multiuser cognitive networks with interference alignment were recently proposed in [12]. These algorithms aimed to maximize the throughput of secondary users, the energy efficiency of the network and the requirements of secondary users, while guaranteeing the quality-of-service of the primary user.

Some scheduling fairness and power control schemes were presented in [13] for multiuser cognitive networks with opportunistic scheduling among the secondary users. In [14], Khan et al. derived the exact outage and error probabilities for multiuser cognitive networks with opportunistic scheduling and Nakagami-*m* fading channels. In general, two important issues need to be considered when designing any multiuser network: the sum-rate capacity and the fairness among users. The maximum-rate or conventional scheduling maximizes the sum capacity at the expense of unfairness among users; whereas, the proportional fair user selection scheme satisfies fairness among users at the expense of system sum-rate [15]. Therefore, the selection of the scheduling scheme depends on the system requirements and nature of the system. Although the proportional fair scheduling could be helpful for users of weak channels, the loss that happens in the throughput when this scheduling scheme is used, can be large in situations where users are scattered across the cell [16]. In summary, the opportunistic and evenly the generalized order user schedulers are suitable for systems where the overall sum-rate capacity or the overall performance is the main requirement; whereas, the proportional fair scheduling schemes are more desirable in systems where the fairness among users is the first priority.

From our reading of the literature in the area of multiuser cognitive networks, we noticed that the most commonly used secondary user selection scheme in these networks is the opportunistic scheduling. In this scheme, the user with the best instantaneous channel is selected every time for data transmission or reception. Also, we noticed that most of the papers on multiuser cognitive networks assumed perfectly estimated channels and ignored the effect of imperfect channel estimation on the system performance. There exist several situations in wireless networks where the opportunistic scheduling could fail, among which are: in the presence of imperfect channel state information where the scheduling unit could fail in error in selecting the best user (user of best channel) among the available users, in the presence of outdated channel information where the user which had the best channel at the selection time instant could not be the best at the transmission time instant, and in cases where, while the user of the best channel is waiting to be scheduled by its base station, gets scheduled by other one. In such situations, the first base station can assign the system resources to the second best or any other user in its area as in handoff conditions. An efficient selection scheme which can deal with such situations is the generalized order user scheduling. In this scheme, the user with the second or even the *N*th best channel is selected instead of the best user (user with the best channel) for transmitting or receiving data. This scheme was first proposed in literature to select among antennas [17], then, it was presented to select among relays in relay networks [18], and recently, it was used to select among users in multiuser relay networks [19]. The generality and effectiveness of the generalized order user selection scheme and the importance of channel estimation process and its role in cognitive networks motivated us to contribute in this area of research. The previous papers on multiuser cognitive networks with opportunistic scheduling are special cases of the presented generalized order user scheduling multiuser cognitive network.

Another important scenario that could be seen in multiuser cognitive networks is the scenario where the primary users use orthogonal spectrum bands. An important application of this scenario is in long term evolution (LTE) networks where the orthogonal frequency division multiple access (OFDMA) technique is used in the downlink transmission in which different sub-channels and bands are assigned for different users. Another application of the proposed scenario is in IEEE 802.22 wireless regional area networks (WRANs) where the OFDMA is a candidate access method. Finally, this scenario could be seen in GSM cellular systems where the primary and secondary users are assigned the system resources using the FDMA/time division multiple access (TDMA) technique. The importance of proposing and evaluating the performance of multiuser cognitive networks with multiple primary users using orthogonal spectrums motivated us to consider it in this study along with the scenario where the primary users use the same spectrum.

In this paper, we introduce and study the performance of multiuser cognitive generalized order user selection network with multiple primary users in the presence of imperfect channel estimation. Two scenarios are considered: primary users with the same spectrum and primary users with orthogonal spectrums. In the considered secondary user selection scheme, the user with the first or even the *N*th best signal-to-noise ratio (SNR) is scheduled by the scheduling unit and assigned the system resources. Closed-form expressions are derived for the outage probability, average symbol error probability (ASEP), and ergodic channel capacity of the secondary system assuming Rayleigh fading channels. The interference from a primary transmitter on secondary users is also studied in this paper via deriving of closed-form expressions for the outage probability. Furthermore, the performance is studied at the high SNR regime where approximate expressions are derived for the outage probability and ASEP in addition to the derivation of the diversity order and coding gain of the system. Firstly, the probability density function (PDF) of the SNR conditioned on the statistics of the secondary cell-to-primary cell channels is derived. Then, this PDF is used to obtain the cumulative distribution function (CDF) of the SNR at the selection scheme combiner output which is then used to evaluate the various performance measures. Independent non-identically distributed (i.n.i.d.) generic case of secondary users channels is considered in the analysis. The effects of the number of primary users, the number of secondary users, the order of selected secondary user, the interference from a primary transmitter and channel estimation error on the system performance are illustrated via providing some simulation and numerical examples.

This paper is organized as follows. Section 2 presents the system and channel models. The exact performance evaluation is conducted in Section 3. Section 4 provides the asymptotic performance analysis. Some simulation and numerical results are discussed in Section 5. Finally, Section 6 concludes the paper.