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Non-orthogonal multiple access protocol for overlay cognitive radio networks using spatial modulation and antenna selection

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ABSTRACT

In this paper we propose a novel spectrum sharing protocol for overlay cognitive radio networks using non-orthogonal multiple access (NOMA), spatial modulation (SM) and antenna selection (AS). The proposed protocol allows a secondary transmitter (ST) to transmit simultaneously to both a primary receiver (PR) and a secondary receiver (SR) using SM. The usage of NOMA and SM will increase the spectral efficiency for both PR and SR with reduced detection complexity than the case without NOMA in which the detectors are required to jointly detect both SM symbols at each receiver. The application of AS at ST with regards to PR provides higher quality transmission for PR without affecting the performance of SR. The performance of the proposed protocol is investigated by derivations of upper bounds on the average symbol error probabilities at PR and SR and by Monte Carlo simulations. Analytical and simulation results show that the proposed protocol offers efficient spectrum utilization over spectrum sharing protocols proposed recently that uses SM – to convey the primary data to PR through the amplitude phase modulation technique and the secondary data to SR through the index of the active antenna.

1. Introduction

Cognitive radio (CR) was proposed as a promising technology for enhancing the utilization of the radio spectrum, since it could efficiently resolve the spectrum scarcity versus the under-utilization dilemma caused by the conventional fixed spectrum allocation [1]. Research on CR has been divided into three main spectrum-sharing paradigms: interweave, underlay, and overlay. In this paper we consider the overlay model where the secondary users (SUs) are assumed to be equipped with advanced signal processing and encoding techniques to maintain or enhance the communication of the primary users (PUs) while also gaining access to the spectrum for their own communication [2].

To tackle the less-efficient use of the scarce spectrum various multiplexing techniques have been recently proposed, like spatial modulation (SM) and non-orthogonal multiple access (NOMA), where NOMA exploits the power domain and SM exploits the spatial domain to efficiently improve the spectrum utilization. Spatial modulation (SM) was introduced in [3] as a spatial multiplexing technique that effectively remove inter channel interference and synchronization issues amongst antennas in multiple input multiple output (MIMO) systems; since only one transmit antenna is allowed to transmit at any transmission period. SM increases the spectral efficiency by utilizing the active antenna index for conveying information besides the usage of conventional amplitude and phase modulation (APM) techniques. Inspired by SM, some variants of SM schemes have been investigated such as: spatial shift keying (SSK) that reduces the complexity of SM by utilizing the spatial domain only, and generalized spatial modulation (GSM) that increases the spectral efficiency of SM, by allowing more than one transmit antenna to be active at a time, in a tradeoff with increased receiver complexity [4,5]. For SM, the optimal maximum likelihood (ML) detector that jointly estimates the active antenna index and the transmitted APM symbol was proposed in [6]. For further improvement in the performance of SM, antenna selection (AS) was investigated. In [7], the authors proposed two AS schemes for SM systems, the Euclidean Distance optimized AS (EDAS) and Capacity Optimized AS (COAS). Both schemes were shown to provide significant performance compared with SM without AS, while EDAS outperforms COAS but with increased computational complexity [8].

The application of spatial modulation (SM) in overlay cognitive radio networks has been recently investigated. In [9], the authors considered using SM at the secondary transmitter to relay the primary transmitter APM symbol using decode-and-forward (DF) technique while the symbol intended for the secondary receiver is used to select the transmitting antenna index. The performance of the protocol is evaluated by computing upper bounds on the bit error probabilities

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(BEP) for single antenna primary and secondary receivers. The authors of [9] extended their work in [10] for different relaying strategies: fixed and incremental amplify and forward, and selective decode and forward, with upper bounds on the BEP have been derived. In [11], the authors considered the same idea of [9] but using amplify and forward and multiple antenna primary and secondary receivers. The performance is evaluated by deriving upper bounds for the average symbol error rates at the primary and secondary receivers.

On the other hand, NOMA with successive interference cancellation (SIC) is a promising spectrally efficient multi-user access scheme for 5G mobile networks, where multiple users are served at the same time span and frequency band, but with different power levels [12]. The performance of NOMA improves when the difference in channel gains between users is large [13]. With NOMA, users with higher channel gains are allocated less power, and hence they can decode their intended information by applying SIC. User pairing can be used to improve the performance of NOMA, by pairing the users with more distinctive channel gains with each other [14]. To further increase the spectral efficiency of NOMA, recent studies investigated the application of NOMA with multiple antenna systems, for example in [15,16] the authors studied the performance of NOMA over MIMO channels. The researchers in [17] investigated NOMA with SM in a downlink multiuser transmission and the performance has been compared with orthogonal multiple access-based SM (OMA-SM) and transmit antenna grouping based SM (TAG-SM) schemes. In [18] the authors proposed a hybrid detection scheme to combine SM and NOMA in the uplink side. The application of NOMA in CR networks has recently attracted many researchers to investigate problems related with outage probability, capacity analysis and power allocation schemes to further improve the system performance [19]. For example in [20] the authors studied the power allocation problem for NOMA-based CR networks and proposed a low complexity algorithm that guarantees the quality of service requirements for both the PUs and SUs. In [21], the researchers proposed an algorithm to maximize the energy efficiency of a generalized CR inspired NOMA system, subject to both the transmit power constraint and the QoS guarantees for all primary users.

In this paper we propose a spectrum sharing protocol for overlay CR networks using NOMA, SM and AS. The proposed protocol allows the secondary transmitter (ST) to transmit simultaneously to both the primary receiver (PR) and the secondary receiver (SR) using SM. The usage of NOMA and SM will increase the spectral efficiency for both the primary and secondary receivers. With NOMA, SR uses SIC to detect the signal intended for PR and then cancels it to detect its own signal while PR uses direct decoding to detect its own signal considering the intended signal for SR as an interference. This decreases the detection complexity considerably compared to the case without NOMA in which the detectors are required to jointly detect both SM symbols at each receiver. Furthermore, the application of AS at ST in accordance with PR will enhance the performance of PR without affecting the performance of SR. This will ensure that the primary symbol will be sent over one of the channels with high gain (with respect to PR) and the secondary symbol will be sent over one of the channels with low gain (with respect to PR), which will result in a little secondary interference at PR – compared with the case without AS – and therefore will enhance the performance of PR. On the other hand the new ordering of the antennas of ST is still random with respect to SR and hence will not affect the performance of SR on the average. The performance of the proposed protocol is investigated through derivations of upper bounds for the average symbol error probabilities (SEP) at PR and SR and through Monte Carlo simulations.

This paper is organized as follows. Section 2 presents the system model and the proposed overlay CR NOMA-SM protocol description with and without AS. The performance analysis of the primary and secondary users is presented in Section 3. The analytical and simulation results are discussed in Section 4. Finally Section 5 concludes the paper.

Notation: Throughout this paper bold lower and upper-case letters are used for vectors and matrices, respectively. $Re\{\cdot\}$ denotes the real part of a complex number. $(\cdot)^T$ and $(\cdot)^H$ are used to represent the transpose and Hermitian transpose of a vector (or a matrix), respectively. $||\boldsymbol{x}||$ is used to represent the L_2-norm of a vector $\boldsymbol{x}$. Circularly symmetric complex Gaussian random variable X with mean μ and variance σ^2 is represented by $X \sim \mathbb{C}\mathcal{N}(\mu,\sigma^2)$. $Q(\cdot)$ denotes the well-known Gaussian Q-function.

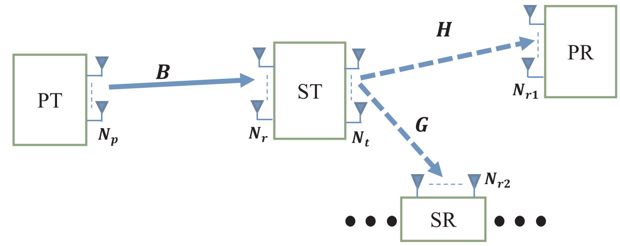

Fig. 1. System model of the overlay CR network. The solid line shows the channel matrix $\boldsymbol{B}$ and also indicates the first phase. The dashed lines show the channel matrices $\boldsymbol{H}$ and $\boldsymbol{G}$ and indicates the second phase. The black dots indicates multiple SRs that are served by ST.

2. System model

In this paper we consider an overlay cognitive radio network as shown in Fig. 1. The primary network consists of a primary transmitter (PT) with N_p transmit antennas, and a primary receiver (PR) with N_{r1} receive antennas. The secondary network consists of a secondary transmitter (ST) with N_t transmit antennas and N_r receive antennas and a secondary receiver (SR) with N_{r2} receive antennas. ST acts as a relay that cooperatively assists the communications between PT and PR while gaining access to the spectrum to convey its own information to SR. ST can be a secondary base station that needs to communicate with multiple secondary receivers, hence to achieve the most benefits of NOMA, ST is assumed to perform user pairing by selecting the SR with the highest channel gain (among all other SRs represented by dots in Fig. 1) with respect to the channel gain of the intended PR. ST uses decode and forward algorithm to relay the message of PT to PR. It is assumed that no direct link exists between PT and PR, like the case of a cell-edge user that experiences very low SNRs. Throughout this paper all nodes are constrained to operate in a half-duplex mode. We assume independent Rayleigh fading for all transmitter–receiver pairs. The channel matrices for the PT-ST, ST-PR, and ST-SR links are $\boldsymbol{B}$, $\boldsymbol{H}$ and $\boldsymbol{G}$ with entries $b_{ij}\sim\mathbb{C}\mathcal{N}(0,1)$, $h_{ij}\sim\mathbb{C}\mathcal{N}(0,\sigma_h^2)$ and $g_{ij}\sim\mathbb{C}\mathcal{N}(0,\sigma_g^2)$ respectively. Furthermore, the noise at any node is modeled as $\mathbb{C}\mathcal{N}(0,\sigma_n^2)$. P_p and P_s are the transmit powers of PT and ST, respectively. It is assumed that perfect channel state information (CSI) is available at all receivers.

As shown in Fig. 1, the communication process can be done in two phases as follows:

2.1. The first phase

PT is considered to use SM to transmit its message to ST. With SM PT divides its message into two parts, the first part ($\log_2 M$) bits select a symbol x_q from the M-ary constellation set, while the second part ($\log_2 N_p$) bits select antenna i out of N_p transmit antennas to transmit the selected symbol x_q. Hence the received signal at the receiving antennas of ST can be written as:

$$\boldsymbol{y}_{ST} = \sqrt{P_p}\boldsymbol{b}_i x_q + \boldsymbol{n}_{ST} \tag{1}$$

where $\boldsymbol{b}_i (1 \leqslant i \leqslant N_p)$ is the i^{th} column of $\boldsymbol{B}$ and represents the channel vector between the active antenna at PT and the receiving antennas at ST. $\boldsymbol{n}_{ST}$ is the noise vector at ST. For equally likely symbols, the optimal detector at ST based on the ML principle is given as: