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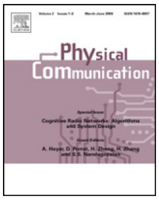

Full length article

Distributed spatial modulation with dynamic frequency allocation

Kunal Sankhe *, Sachin Chaudhari, Garimella Rama Murthy

Signal Processing and Communication Research Center, International Institute of Information Technology, Hyderabad, India

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A B S T R A C T

This paper proposes a distributed implementation of spatial modulation (SM) using cognitive radios. In distributed spatial modulation (DSM), multiple relays form a virtual antenna array and assist a source to transmit its information to a destination. The source broadcasts its signal, which is independently demodulated by all the relays. Each of the relays then divides the received data in two parts: the first part is used to decide which one of the relays will be active, and the other part decides what data it will transmit to the destination. An analytical expression for symbol error probability is derived for DSM in independent and identically distributed (i.i.d.) Rayleigh fading channels. The analytical results are later compared with Monte Carlo simulations. Further, an instantaneous symbol error rate (SER) based selection combining is proposed to incorporate the direct link between the source and destination with existing DSM. Next, DSM implementation is extended to a cognitive network scenario where the source, relays, and destination are all cognitive radios. A dynamic frequency allocation scheme is proposed to improve the performance of DSM in this scenario. The frequency allocation is modeled through a bipartite graph with end-to-end SER as a weight function. The optimal frequency allocation problem is formulated as minimum weight perfect matching problem and is solved using the Hungarian method. Finally, numerical results are provided to illustrate the efficacy of the proposed scheme.

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1. Introduction

The hugely popular multiple-input and multiple-output (MIMO) technology exploits multiple antennas to achieve different gains such as multiplexing, diversity and/or beamforming [1]. However, these gains are often accompanied by a significant increase in computational complexity and cost of a receiver. One approach to overcome these issues is to use Spatial Modulation (SM) [2,3]. In SM, a group of information bits is mapped into two constellations: a signal constellation based on modulation scheme and a spatial constellation to encode the index of the transmit antenna. At any time instant, only one transmit antenna is active, whereas other transmit antennas radiate zero power. This completely avoids inter-channel interference at the receiver and relaxes the stringent requirement of synchronization among the transmit antennas. Moreover, unlike the conventional MIMO system, SM system does not require multiple RF chains at the transmitter. The index of active transmit antenna is used as an additional source of information. At the receiver, a low complexity decoder such as Maximum Receive Ratio Combining (MRRC) is used to estimate the index of active transmit antenna, after which the transmitted symbol is estimated. Using these two estimates, a spatial demodulator retrieves the group of information bits. A complete introduction on SM is presented in [4]. A special case of SM called Space Shift Keying (SSK) is proposed in [5].

Recent studies [6,7] have shown that SM can outperform other state-of-the-art MIMO schemes in terms of computational complexity if many antennas are available at the transmitter. Unfortunately, this makes SM useful only in the downlink of the cellular network, where a base station can be equipped with a large number of antennas. On the other hand, use of multiple antennas in mobile terminals has practical limitations. Besides constraints on complexity and cost, decreasing terminal size restricts the application of SM in the uplink of cellular network. To overcome these problems, distributed spatial modulation (DSM) presents a promising solution, where a set of neighboring mobile terminals assist the source in conveying its information to the destination [8]. The key idea behind DSM is that multiple cooperative relays share their antennas to form a virtual antenna array (VAA) and apply SM principle in a distributed manner. The DSM system overcomes the limitations of heavy shadowing effects while expanding network coverage. Moreover, only one relay is selected to forward the source's information to the destination, thus saving overall transmit power of the system. Over the recent years, several attempts have been

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* Corresponding author.
E-mail addresses: kunal.sankhe@research.iiit.ac.in (K. Sankhe), sachin.chaudhari@iiit.ac.in (S. Chaudhari), rammurthy@iiit.ac.in (G. Rama Murthy).

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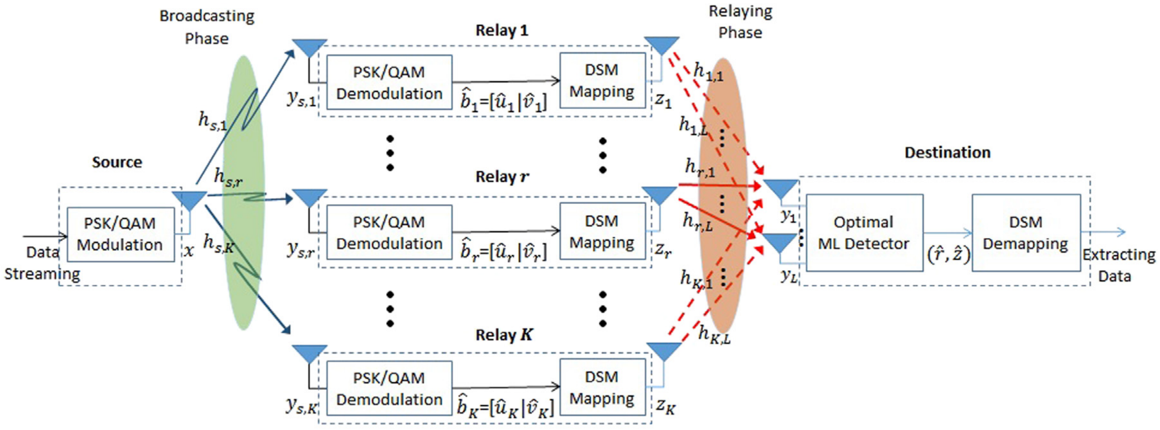

Fig. 1. DSM system model including one single-antenna source, K single-antenna relays, and the destination with L receive antennas. The source broadcasts its signal (x), which is independently demodulated by each relay. Each of the relay then divides the received data ($\hat{b}_r$) in two parts: the first part ($\hat{u}_r$) is used to decide which one of the relays will be active, and the other part ($\hat{v}_r$) decides what data it will transmit to the destination. The received signal at the destination is applied to an optimum ML-detector to determine the estimated index of the active relay ($\hat{r}$) and transmitted symbol ($\hat{z}$) by the active relay. Information bits are retrieved from these estimates by using DSM mapping table.

made to extend the concept of SM/SSK to a distributed scenario, both for the amplify-forward (AF) and decode-forward (DF) protocols. The authors of [9] have studied the performance analysis of an SSK-based AF relay network. In [10], using the idea of SSK, a cooperative transmission scheme is considered both for the AF and DF protocols. In [11], the application of distributed SSK to the uplink cellular network is studied. In [12], a distributed SM scheme, where the relays have their own data, has been studied. In this paper, we focus our attention on application of DSM in the uplink of cellular network. An analytical expression of SER is derived for DSM under i.i.d. Rayleigh fading channels. The analytical results are compared with simulation results, which shows a closed match for a wide range of SNR. Further, we consider the direct path between the source and destination in addition to source–relay and relay–destination links to achieve spatial diversity. The destination chooses either source–destination direct link or DSM to decode the data using instantaneous SER based selection combining.

Rapid growth in wireless services over the past decade has resulted in spectrum congestion. Interestingly, spectrum utilization measurements carried by the Federal Communications Commission (FCC) [13] have shown that most of the licensed networks have low spectrum utilization. This, along with fixed allocation policy, has resulted in an apparent spectrum scarcity. Cognitive radio provides an efficient solution for this problem through dynamic spectrum access [14,15]. The main idea in dynamic spectrum access is that cognitive radios (also called secondary users) are allowed to opportunistically utilize licensed bands as long as harmful interference caused to the licensed users (also called as primary users) is within prescribed limits. Recently, there has been a growing interest in the integration of cognitive radio capability into cooperative communications [16]. In this paper, we investigate the application of the DSM in relay-assisted cognitive radio network.

Specific contributions of this paper are

(1) An analytical expression of symbol error rate (SER) is derived for the DSM system in independent and identically distributed (i.i.d.) Rayleigh fading channels. Simulation results are provided to confirm the theoretical analysis.
(2) By considering the direct link between the source and destination, a spatial diversity is achieved by combining the source–destination and relay–destination links at the destination. The destination chooses either direct link or DSM to decode the data, which provides the minimum instantaneous SER.
(3) The application of DSM is extended to CR network, where secondary relays assist the secondary source in conveying its information to the cognitive base station using DSM protocol.
(4) A dynamic frequency allocation scheme is proposed for DSM based CR network to assign unutilized licensed frequencies to cognitive relays. The frequency allocation problem is formulated with an objective to minimize the sum total of end-to-end SER of links between the source and destination via each relay. It can be shown that there is significant performance improvement over the traditional random frequency allocation scheme.

The rest of this paper is organized as follows: Section 2 presents a system model for DSM based CR network. This is followed by derivation of analytical SER of DSM in Section 3. Section 4 discusses DSM with instantaneous SER based selection combining. In Section 5, we provide dynamic frequency allocation algorithm for DSM based CR network. Section 6 presents theoretical and simulation results. Section 7 concludes the paper.

2. Distributed spatial modulation

2.1. System model and notations

We consider a CR network topology with one single-antenna source (S), K single-antenna relays (R_r, with $r = 1, 2, \ldots, K$) and a destination (D) with multiple receive antennas, as depicted in Fig. 1. This network topology emulates the uplink of the cognitive cellular network, where the source and relays are secondary users and the destination is cognitive base station. The source and relays opportunistically access licensed spectrum band based on the interweave cognitive radio approach. The following assumptions are made: (a) All nodes operate in half duplex mode. (b) The coverage of the source extends to include relays, but not the destination due to deep fading, heavy path loss or shadowing effects. It means no direct path exists between the source and destination and therefore, relays assist the source in transmitting its information to the destination using DSM protocol. (c) Relays are either dedicated network elements or idle users, which do not have data to transmit. (d) A lexicographic labeling $\mathbf{ID}_{R_r}$ is used to assign a unique digital identifier to each relay. For example, for $K = 4$, relays R_1, R_2, R_3 and R_4 will have digital identifiers $\mathbf{ID}_{R_1} = 00, \mathbf{ID}_{R_2} = 01, \mathbf{ID}_{R_3} = 10$ and $\mathbf{ID}_{R_4} = 11$ respectively each of $\log_2(K)$ bits.

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