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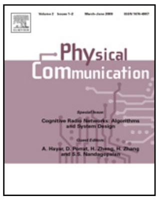

Full length article

Orthogonal space–time block coding over dirty paper channel: Outage capacity analysis[☆]

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ABSTRACT

We analytically prove that the outage capacity of the multiple input multiple output (MIMO) which is affected by interference, that is non-causally available as well as the channel state information (CSI) for all users at the transmitter, has the free interference outage capacity. Specifically, Orthogonal space–time block coding (O-STBC) with two transmit antennas and arbitrary number of receive antennas is used for transmission and reception. We modify the random variable U which was proposed by Costa (1983) to account for the availability of the CSI at both the transmitter and receiver. Further, we use lattice dirty paper coding (DPC) to show that an interference free channel capacity can be achieved in the MIMO-OSTBC system. First, we derive the equivalent noise seen by the receiver using an equivalent lattice based dirty paper code. Then the optimal value of the power inflation factor is derived. Next, the channel capacity of the equivalent modulo lattice channel is computed. Finally, performance results in the case of various number of receive antennas are presented and showed that significant reduction in frame error probabilities can be obtained over a system that uses no interference cancellation.

1. Introduction

Communicating over multiuser wireless system is more challenging than single user due to the additional degrees of freedom entailed by canceling or avoiding interference. Thus, reducing the effect of this interference at either the transmitter or receiver is the goal of many encoding schemes. For instance, in the case of Gaussian interference channel with very strong interference, each destination can get single user rate by decoding both the desired and the other user messages [1]. In addition, by employing DPC, the transmitter can completely mitigate the multiuser interference such that the interference-free rate performance is achieved. In this regard, an efficient known interference cancellation was derived by Costa [2]. In his pioneer work, Costa proved that the channel capacity of a communication system in which the interference is available in a noncausal manner to the transmitter but not the receiver is the same as the capacity when there is no interference. Such interference cancellation schemes are being employed in a wide range of applications such as MIMO channels and fading channels, in the case of side information at the transmitter [3–5]. The capacity limits of the dirty paper channel have been widely studied for the single input single output (SISO) channel with perfect noncausal interference [2], faded noncausal interference [6], and noisy causal interference [7]. These capacity limits have been extended to MIMO systems such as the broadcast channel [5, 8–10] and the cognitive Z-interference channel (ZIC) [11]. Simultaneous to these theoretical developments, practical DPC techniques have also been proposed for the SISO additive Gaussian channel [12–14], the MIMO broadcast channel [15] and for cognitive radio channels [16].

In their work, Gelfand and Pinsker [17] proved that the capacity of a discrete memoryless channel $p(y|x, s)$ with

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noncausal additive side information S available only to the transmitter is given by

$$C = \max_{p(u,x|s)} \{I(U;Y) - I(U;S)\} \tag{1}$$

where U is an auxiliary random variable. Costa [2] used the result in (1) to show that interference-free channel capacity can be achieved for the problem of transmission over Gaussian channel corrupted by additive interference. In this model, the received signal is given as

$$Y = X + S + Z. \tag{2}$$

In his path to achieve the interference free channel capacity, Costa designed the random variable U as $U = X + \beta S$, where β is the power inflation factor. In addition, Costa introduced a new transmission strategy, which is commonly referred to as dirty paper coding (DPC) that achieves this capacity. In this coding technique, the transmit signal is adapted in the direction of the available interference to satisfy the power constraint at the transmitter. Moreover, the authors in [18] transformed the channel model in (2) into a modulo lattice additive noise (MLAN) channel model. They also showed that the capacity of this MLAN channel is as asymptotical as when there is no interference.

In this paper, we mainly consider the problem of communicating over MIMO-OSTBC channel with side information at the transmitter as depicted in Fig. 1. For instance, consider a cognitive ZIC [12,11] in which one of the two transmitters is cognitive. In this channel model, one of the two users (the first) has an interference-free channel whereas the other user, the cognitive user, is affected from the transmission of the first user. This interference from the first user reduces the achievable rate over the second link. Thus, the availability of this interference at the cognitive transmitter enables employing DPC such that the effect of this interference is completely removed. In this paper, the interference signal is assumed to be available at the cognitive transmitter in a noncausal manner. For instance, the interference signal from the first user is supposed to be available at the cognitive transmitter before these two senders start transmission of their messages. Practically, the first user might be a base station communicating with its destination which is a mobile user at the cell-edge. The cognitive transmitter and its destination represent additional users in the system that wish to communicate directly with each other.

The model that is considered in this paper contains a sender with n_T transmit antennas and n_R receive antennas. Let $\mathbf{X} \in C^{n_T \times T}$ is the transmitted signal matrix spanning T symbol intervals with 0 mean and covariance matrix Σ_X, and has a power constraint of $\mathrm{Tr}(\Sigma_X) \leq P_X$. Then, the multiple input multiple output channel with interference is given as [3,16]

$$\mathbf{Y} = \mathbf{HX} + \mathbf{GS} + \mathbf{N} \tag{3}$$

where $\mathbf{Y} \in C^{n_R \times T}$ is the received signal matrix, $\mathbf{N} \in C^{n_R \times T}$ is the additive white Gaussian noise matrix with 0 mean and covariance matrix Σ_Z. Further, $\mathbf{S} \in C^{n_I \times T}$ is the interference matrix in which n_I is the number of transmit antennas at the interfering source. This interference is assumed to be non-causally known to the transmitter but not to the receiver. In addition, $\mathbf{S}$ is assumed to be a 0 mean Gaussian distributed random variable with covariance matrix Σ_S and power constraint $Q = |\Sigma_S|$. The channels $\mathbf{H} \in C^{n_R \times n_T}$ and $\mathbf{G} \in C^{n_R \times n_I}$ are modeled as quasi static fading matrices from the transmitter and interfering sources, respectively, to the receiver. We assume that these channels are known perfectly to both the transmitter and the receiver [19,15]. For instance, the receiver could measure both these channels and use a feedback link to send them to the transmitter. Further, the transmitted codeword, the interference signal and the noise signals are assumed to be independent.

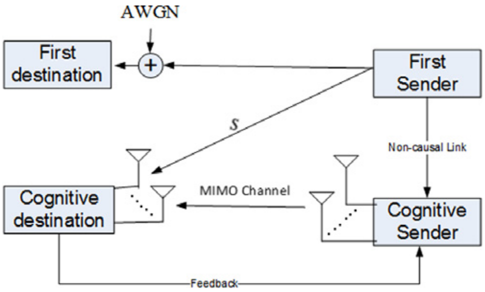

Fig. 1. ZIC with cognition at one of the two receivers. DPC scheme and multiple transmit antennas are employed at the cognitive transmitter.

The main results of this paper are summarized as follows.

(1) In order to achieve the interference-free channel capacity in MIMO-OSTBC system, we first transform the MIMO channel into its equivalent MLAN channel by using lattice based DPC described in [20,18]. Next, we compute the equivalent interference as seen by the receiver. Then, the power inflation factor which is used to minimize the equivalent noise is computed. And finally, the capacity formula of the equivalent modulo lattice channel is derived.

(2) We prove that the optimal inflation factor should be equal for every two consecutive time slots at the transmitter and for all receive antennas. Remember that two adjacent symbol periods are used for transmission whereas arbitrary number of antennas is used at the receiver.

(3) Even though that DPC is applied for systems with perfect channel state information at the transmitter, the effect of having noisy CSI has to be quantified. In this paper, we quantify the system's deterioration due to uncertain channel state information at the transmitter.

The remaining part of the paper is organized as follows. The transmitter and receiver structures are fully studied in Section 2. Lattice DPC, which is used to (i) achieve the interference free channel capacity and (ii) derive the equivalent noise seen by the receiver as well as the power inflation factor, is studied for MIMO-DPC in Section 3. Then, the effect of having uncertain channel state information is analyzed in Section 4. After that, system performance and numerical results are presented in Section 5. Finally, Section 6 concludes the paper.

2. System description

In this section, we initially present the basic structure of the proposed encoder and decoder. We then prove that the