Broadcast Underlay Cognitive Radio with Dirty Paper Coding over Fading Channels

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Abstract

In this paper, the bit error rate (BER) performance analysis of an underlay cognitive radio (CR) network, which is considered as a broadcast scheme, over fading channels, is investigated. Particularly, the underlay CR network is studied as a closed loop multiple antenna system, presented with dirty paper coding (DPC) approach with the aim of allowing the secondary user (SU) transmission to utilize the spectrum resources efficiently and avoiding harmful interference to the primary user (PU) receiver. The proposed approach is capable of achieving the same performance as that of the zero-forcing (ZF) algorithm over Rayleigh fading channels at the SU receiver. We further show that the BER performance of the PU under Rician fading channel is significantly improved for the proposed study. Finally, numerical and simulation results are provided to demonstrate the performance and corroborate the theoretical analysis.

1. Introduction

The limited available frequency bandwidth and the inefficient usage for the radio spectrum necessitate a new communication policy to exploit the unused spectrum holes opportunistically for the existing wireless spectrum resources. Cognitive radio (CR) systems have been proposed as a new approach for wireless communication systems to utilize the existing spectrum resources much more efficiently [1-3]. Spectrum utilization can be increased by allowing the unlicensed secondary users (SUs) to utilize the licensed band in the absence of the primary user (PU). In CR terminology, the PU is defined as the user who has legacy rights and higher priority to use the licensed spectrum. On the other hand, an unlicensed SU has lower priority and is allowed to utilize the idle spectrum holes opportunistically without causing harmful interference to the PU [4-7].

Dirty paper coding (DPC) and multiple-input multiple-output (MIMO) systems in CR networks are techniques that can utilize the spectrum resources efficiently [8-12]. The authors in [13-14] proposed a new broadcast strategy for a MIMO system with M transmit antennas at the transmitter and $N \leq M$ receivers. The capacity of a channel with additive white Gaussian noise (AWGN) and power constraint input were evaluated in [15] with the aim of achieving optimal transmitter design. In [16-17], the authors analyzed the sum rate performance of a quantized channel state information (CSI) based Tomlinson-Harashima (TH) precoding scheme for multi-user MIMO transmission. The sum-rate maximization problem in multi-user multi-relay MIMO system was studied in [18] and the results on the precoding techniques for the source and the relay were presented. In [19], the closed form expressions for the upper bound of the achievable sum-rate were derived for zero-forcing (ZF) beamforming.

Motivated by the above works, in this study, we consider a CR network as a broadcast scheme in which the SU transmitter $(\mathrm{SU_T})$ has perfect knowledge of the CSI of the link between PU transmitter $(\mathrm{PU_T})$ and $\mathrm{SU_T}$. It is also known that, using space division multiple access (SDMA) technique, it could be possible to separate spatially and transmit the signal from the $\mathrm{PU_T}$ to the primary user receiver $(\mathrm{PU_R})$ without any perturbation from the $\mathrm{SU_T}$ [13-14]. However, SDMA suffers from the signal-to-interference plus noise ratio (SINR) degradation at each receiver. Thus, in this study, we present an interference avoidance method based on DPC, applicable for the quadrature amplitude modulation (QAM) signal constellations, resulting in a considerable improvement to SDMA system performance over Rayleigh (special case of Rician fading for $\mathrm{K} = 0$ [20]) and Rician fading channels in the considered CR network.

Although the broadcast schemes for MIMO systems with CSI at the transmitter have been extensively studied (see [21-22]), comparison studies on the bit error rate (BER) performance analysis and spectrum utilization for CR network transmission inspired by DPC over fading channels do not exist in the technical literature. To fill the research gap, in this study, we comprehensively analyze the performance of the BER of the end-to-end signal-to-noise ratio (SNR) when all transmission links are subject to Rician fading channels. Furthermore, we achieve better performance gain for the $\mathrm{PU_R}$ over Rician fading channels.

The rest of the paper is organized as follows: The system model is described in Section 2 presenting a CR network as a broadcast scheme with CSI and QAM signal constellation. The performance analysis of the proposed system model is discussed in Section 3. Section 4 provides the simulation results. Finally, the concluding remarks are given in Section 5.

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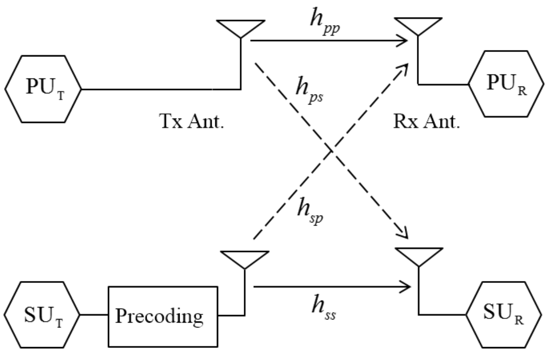

Figure 1. System model of the CR network as a broadcast scheme with CSI

2. System Model

In this section, we consider a CR system with M transmit and N receive antennas, at the PU and SU sides $(M = N = 2)$ as shown in Figure 1. The transmission links between the transmitter and the receiver sides are independent and identically distributed, and are subject to Rician fading, with channel coefficients h_{ij} from the transmitter antenna i $(i = 1, 2, ..., M)$ to the receiver antenna j $(j = 1, 2, ..., N)$, seen in the same figure above, in which $h_{i,j}$ is being used for modelling the $N \times M$ channel matrix $\mathbf{H}$ [13-14]. When the signal transmission for the $\mathrm{PU_T}$ is available, the received signal at the receiver side, $\mathbf{r}_t$ at time t can be given as

$$\mathbf{r}_t = \mathbf{H}x_t + \mathbf{n}_t \tag{1}$$

where $\mathbf{x}_t$ is the $M \times 1$ transmit vector whose i-th element is the signal transmitted from the antenna i at time t. Likewise, the j-th element of $\mathbf{r}_t$ vector is the signal received at j-th receiver at time t. In (1), $\mathbf{n}_t$ is the AWGN term with zero mean and variance of σ^2. We assume that the channel matrix $\mathbf{H}$ is known at the $\mathrm{SU_T}$ that is to say perfect CSI is available at the $\mathrm{SU_T}$ [23].

In the ZF beamforming approach [24], the $\mathbf{x}_t$ can be expressed as

$$\mathbf{x}_t = \frac{\mathbf{H}^* \left(\mathbf{H}\mathbf{H}^*\right)^{-1}\mathbf{s}}{\sqrt{tr\left[\left(\mathbf{H}\mathbf{H}^*\right)^{-1}\right]}} \tag{2}$$

where $\mathbf{H}^*$ is the conjugate transpose (Hermitian) of $\mathbf{H}$, $\mathbf{s}$ is the original information at the transmitter side, and tr is the trace of the matrix. Then the received signal in (1) is obtained as in [13-14]:

$$\mathbf{r}_t = \frac{\mathbf{s}}{\sqrt{tr\left[\left(\mathbf{H}\mathbf{H}^*\right)^{-1}\right]}} + \mathbf{n}_t. \tag{3}$$

We can model (3) as the scaled version of the transmitted signal. Thus, ZF SDMA solution disposes the interference from the signal in the receiver side that is transferred from any other users in the transmitter side. However, average power loss of $\left(tr\left[\left(\mathbf{H}\mathbf{H}^*\right)^{-1}\right]\right)^{1/2}$ is still problem for ZF model that means it performs poorly in low SNRs.

In this context, we consider the method developed in [11-14] while the proposed approach is used for encoding, decoding and constellation scheme as shown in Fig. 1 and Fig. 2, respectively.

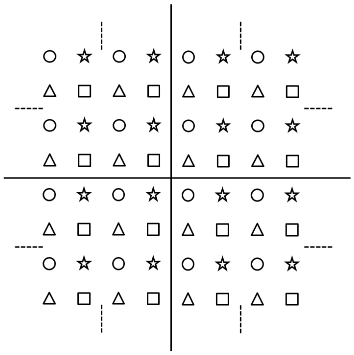

Figure 2. 4-QAM signal constellations [14]

3. Performance Analysis of the Proposed System Model

We consider the BER performance analysis of the proposed system model for Rician fading channel. The channel matrix, $\mathbf{H}$ is given by

$$\mathbf{H} = \begin{bmatrix} h_{pp} & h_{ps} \\ h_{sp} & h_{ss} \end{bmatrix} \tag{4}$$

where h_{ij} is the channel fading from the transmitter antenna i to the receiver antenna j [25]. We assume that $\mathbf{H} \neq 0$ and without loss of generality, $\alpha = \sqrt{|h_{pp}|^2 + |h_{ps}|^2} \neq 0$. Then the $\mathbf{H}$ matrix can be re-expressed as [13-14] $\mathbf{H} = \mathbf{Z}\mathbf{W}$ where

$$\begin{aligned} \mathbf{Z} &= \tfrac{1}{\alpha}\begin{bmatrix} \alpha^2 & 0 \\ h_{sp}h_{pp}^* + h_{ss}h_{ps}^* & -h_{sp}h_{ps} + h_{ss}h_{pp} \end{bmatrix} \\ \mathbf{W} &= \tfrac{1}{\alpha}\begin{bmatrix} h_{pp} & h_{ps} \\ -h_{ps}^* & h_{pp}^* \end{bmatrix} \end{aligned}. \tag{5}$$

The $\mathrm{SU_T}$ transmits the signal $\tilde{\mathbf{x}_t} = \mathbf{W}_t\mathbf{x}_t$ instead of $\mathbf{x}_t$ in order not to generate any interference for the $\mathrm{PU_R}$. Assume that $\mathbf{x}_t = \mathbf{W}^*\mathbf{c}_t$, where $\mathbf{c}_t$ is the $M \times 1$ new transmit vector, then the received signals at $\mathrm{PU_R}$ and $\mathrm{SU_R}$ sides are given by

$$\begin{aligned} r_1 =& \alpha c_1 + n_1 \\ r_2 =& \frac{1}{\alpha}\left(\left(h_{sp}h_{pp}^* + h_{ss}h_{ps}^*\right)c_1\right. \\ &\left. + \left(-h_{sp}h_{ps} + h_{ss}h_{pp}\right)c_2\right) + n_2, \end{aligned} \tag{6}$$

respectively. In (6), c_1 and c_2 are the information sent from the $\mathrm{PU_T}$ and $\mathrm{SU_T}$, successively. Here, $(.)^*$ is the complex conjugation. From the expression for r_1, it is observed that the performance of the $\mathrm{PU_R}$ is similar with the Alamouti scheme with 2 transmit and 1 receive antennas [26]. We choose $c_2 = v - u$, where $u = c_1\left(\left(h_{sp}h_{pp}^* + h_{ss}h_{ps}^*\right)/\left(-h_{sp}h_{ps} + h_{ss}h_{pp}\right)\right)$ and v is the nearest QAM symbol to the u in the signal constellation map which is the desired symbol transmitted from the $\mathrm{SU_T}$. The 4-QAM signal constellation map which is used in the proposed system model is shown in Fig. 2. In this way, the first part of r_2 in (6), $\alpha^{-1}c_1\left(h_{sp}h_{pp}^* + h_{ss}h_{ps}^*\right)$ can be ignored and rewritten as in the following closed form expression, proving that $\tilde{r_2}$ performs almost the same with r_2 [13-14],

$$\tilde{r_2} = \frac{1}{\alpha}\left(\left(-h_{sp}h_{ps} + h_{ss}h_{pp}\right)c_2\right) + n_2. \tag{7}$$

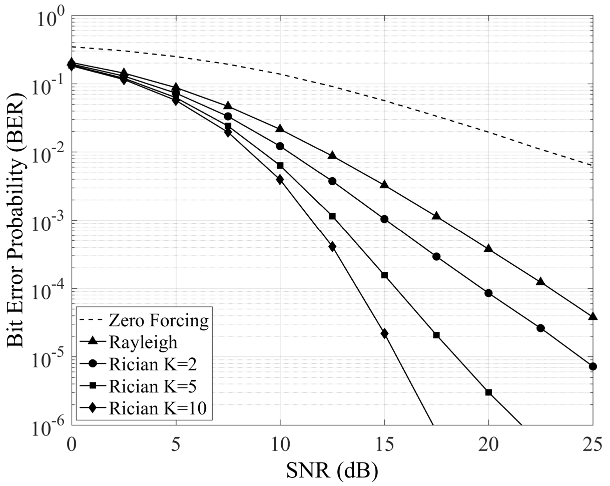

Figure 3. BER performance versus SNR under different channels for the $\mathrm{PU_R}$ perspective

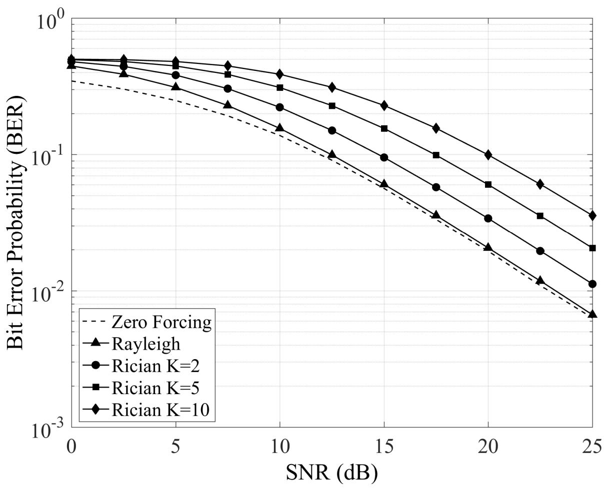

Figure 4. BER performance versus SNR under different channels for the $\mathrm{SU_R}$ perspective

While $\mathrm{PU_T}$ has the transmit power of $(P/2)$, we observe from the numerical results that the mean average power for $\mathrm{SU_T}$ $(\mathrm{P_{SU_T}})$ is exactly equal to $(2P/3)$ which can be derived from the below equation with the help of the QAM constellation map as

$$\mathrm{P_{SU_T}} = P \int_0^1 \int_0^1 \left(\sqrt{\left(P_x{}^2 + P_y{}^2 \right)} \right)^2 \mathrm{d}x \, \mathrm{d}y \qquad (8)$$

where P is the total power of the transmitters, P_x and P_y are the real and the imaginary parts of the 4-QAM symbols, respectively. It is analyzed that the performance of the $\mathrm{SU_R}$ is exactly the same as with the Bell Laboratories layered space-time (BLAST) scheme [27], equipped with 2 transmit and 2 receive antennas.

4. Simulation Results

In this section, the numerical results are presented through the receiver operating characteristics (ROC) curves. 4-QAM with Gray coding BER performance of the proposed system is illustrated in Fig. 3 with different fading channel approaches for the $\mathrm{PU_R}$. The performance over Rician fading channels with the value of Rician K-factor, $(\mathrm{K} = 2, \mathrm{K} = 5, \mathrm{K} = 10)$ are displayed for different values of the SNRs. We also apply ZF scheme for the comparison purposes with the implemented scenario. As it is expected, the system performance improves while the value of Rician K-factor increases. It is clear that the BER performance for the proposed scenario over both the Rayleigh and Rician fading channels outperforms the ZF algorithm.

In Fig. 4, we present the BER results under consideration for the $\mathrm{SU_R}$ over the Rayleigh and Rician distributions. It illustrates the Rayleigh distribution which is slightly similar to ZF approach, outperforms the Rician channel model. The same plot shows that the BER performance degradation with increasing values of K-factor for Rician fading. The reason of this result is basically related with the coefficient of c_2 in (7).

In Rician fading channels, while the K-factor increases, the variance of c_2 coefficient $(-h_{sp}h_{ps} + h_{ss}h_{pp})$ decreases. In addition, the mean value of the c_2 coefficient becomes zero due to minus sign. Then this coefficient leads the signal level of c_2 to the noise level, hence BER degradation occurs. In other words, if the Rician K-factor increases, the interference from the $\mathrm{PU_T}$ is higher at the $\mathrm{SU_R}$. Consequently, the interference is very critical in degrading the BER performance of the $\mathrm{SU_R}$ even if the direct link $\mathrm{SU_T} - \mathrm{SU_R}$ is getting better. On the other hand, this performance degradation under Rician distribution can be easily eliminated by the power allocation among both the $\mathrm{PU_T}$ and $\mathrm{SU_T}$.

5. Conclusion

In this paper, we studied an underlay CR network as a closed loop multiple antenna system presenting with DPC scheme over Rician fading channels. We have provided a rigorous data for the BER analysis for the PU and SU receivers. In the proposed study, we achieved BER performance improvement for the PU under Rician fading channel compared to Rayleigh distribution, while both fading channels outperform ZF algorithm. We have also demonstrated that the performance for the SU over Rayleigh fading is almost the same with the well-known ZF scheme while achieving a low computational complexity.

6. References

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