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BER PERFORMANCE OF GOLDEN CODED MIMO-OFDM SYSTEM OVER RAYLEIGH AND RICIAN FADING CHANNELS

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Abstract— **In this paper, we analyze the Bit Error Rate (BER) performance of Golden coded Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system over Rician multipath fading channel. We also compare the performance of the MIMO-OFDM system using Golden code in Rayleigh and Rician multipath fading channels. We discuss the effects of the presence of line-of-sight (LoS) component in the multipath fading environment which renders the improvement in the overall performance of the Golden coded MIMO-OFDM. This paper discusses the performance of Golden codes in a frequency selective Rician fading channel. To deal with the frequency selective fading channel, we use the OFDM (Orthogonal Frequency Division Multiplexing) modulation. The BER performance of the Golden coded MIMO-OFDM system under several propagation conditions has been evaluated.**

Keywords—MIMO, OFDM, Golden STBC, Rayleigh fading, Rician fading.

I. Introduction

With the advent of next Generation (4G) broadband wireless communications, the combination of Multiple-Input Multiple-Output (MIMO) wireless technology with Orthogonal Frequency Division Multiplexing (OFDM) has been recognized as one of the most promising techniques to support high data rate and high performance [1]-[3].The transmitted signal travels through several different paths toreach the receiver. The received signal includes multiple versions of the transmitted waveform each of which is attenuated by and delayed in time leading to the distortion of the signal. The multipath effect causes the MIMO channels to be frequency selective for high data rate transmissions. Orthogonal Frequency Division Multiplexing (OFDM) [4] has become a popular technique for transmission of signals over wireless channels, which transforms frequency selective fading channel into parallel flat fading channels. OFDM is a multicarrier modulation technique where the subcarriers are mutually orthogonal which in turn avoids Inter Carrier Interference (ICI) and ensures efficient utilization of bandwidth. The MIMO-OFDM has a great potential to meet up the stringent requirement for boosting up the transmit diversity and mitigation of the detrimental effects due to frequency selective fading [5].

Designing Space-Time Block Codes (STBC) for frequency selective MIMO channels is well motivated by broadband applications, where multi-antenna systems have to deliver multimedia information content at high data rates[6]. Furthermore, STBC are used to improve MIMO performances by providing a temporal and spatial multiplexing modulation [7], [8].The seminal code in this category is Alamouti space-time block code which has been proposed in 1998 [9]. Many other codes have been proposed in an attempt to achieve maximum diversity in the channel at various transmission rates [10], [11]. The Golden STBC, which has been proposed in 2005 [12], is a full-rate, full-diversity perfect STBC that has a maximum coding gain for 2X2 MIMO system. The Golden code has been studied in various MIMO-OFDM applications [13]-[15]. Nevertheless, the performance of MIMO-OFDM system using Golden STBC, in an environment where multipath effect predominates, has not been thoroughly studied.

In our work, we analyze the performance of MIMO-OFDM system using the Golden STBC in Rayleigh and Rician frequency selective fading channels. Further, we compare the performance of Golden coded MIMO-OFDM system over Rician frequency selective fading channels with different K factors, where K is the specular-to-diffuse ratio of the received signal. We show the expected significant improvement in the performance of the Golden Coded MIMO-OFDM system in the presence of line-of-sight (LoS) component.

The rest of the paper is organized as follows. In the following section, we present the review of Golden STBC. In Section III, system model of Golden coded MIMO-OFDM is

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described in which we discuss transmitter, channel and receiver models considered in this work. In section IV, we present simulation results for different channel models and compare them. Finally a conclusion is given in section V.

II. Review of Golden STBC

The 2X2, Golden Code is represented as [12],

$$X = \frac{1}{\sqrt{5}}\begin{bmatrix}\alpha(a+b\theta) & \alpha(c+d\theta)\\ i\sigma(\alpha)(c+d\sigma(\theta)) & \sigma(\alpha)(a+b\sigma(\theta))\end{bmatrix}$$

where a, b, c and d are information symbols which can be taken from any M-QAM constellation and

$$i = \sqrt{-1}$$

$$\theta = \frac{1+\sqrt{5}}{2} = 1.618 \text{ (Golden number).}$$

$$\sigma(\theta) = \frac{1-\sqrt{5}}{2} = 1-\theta$$

$$\alpha = 1+i-i\theta = 1+i\sigma(\theta)$$

$$\sigma(\alpha) = 1+i-i\sigma(\theta) = 1+i\theta$$

III. System Model

A. Transmitter:

Following the terminology of [18], let us consider system with N_t=2 transmit antennas and N_r=2 receive antennas, signaling over a frequency selective MIMO channel using OFDM modulation per antenna as shown in Fig. 1. We first generate binary sequence which is then Quadrature Amplitude Modulation (QAM) modulated. The QAM symbol streams are encoded via Golden STBC. Once we obtain Golden coded symbols, $2M_0$ complex valued symbolsare grouped to form parallel input set to the OFDM modulator. For Golden STBC we can write

$$x_n^1(k) = [\alpha(a+b\theta)_t \quad \alpha(c+d\theta)_{t+T}] \tag{1}$$

$$x_n^2(k) = [i\sigma(\alpha)(c+d\sigma(\theta))_t \quad \sigma(\alpha)(a+b\sigma(\theta))_{t+T}] \tag{2}$$

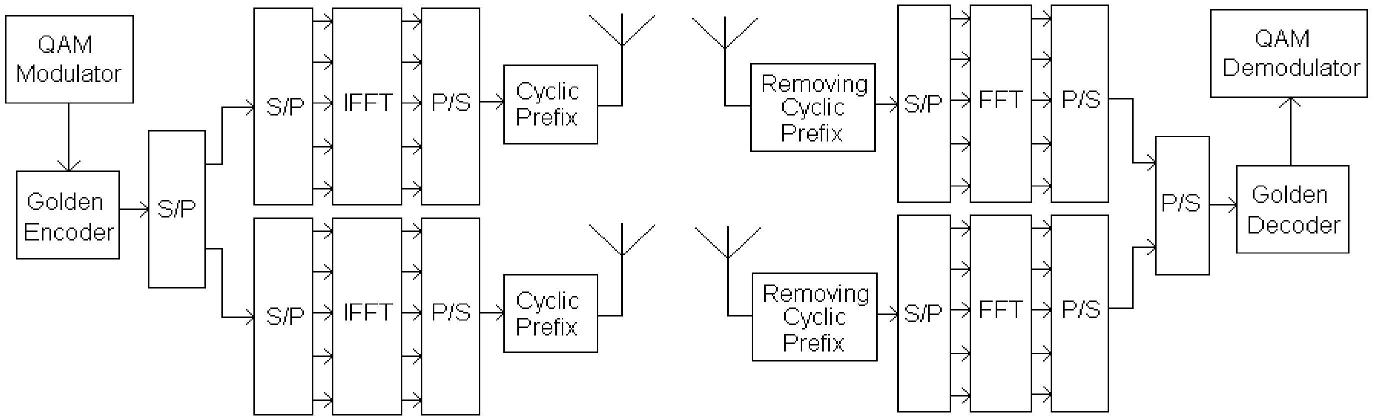

Fig. 1. Golden STBC MIMO-OFDM Transceiver.

where a,b,c and d are QAM modulated symbols and $x_n^1(k)$, $x_n^2(k)$ are Golden modulated symbols sent to OFDM modulators at transmitter 1 and 2 respectively. t, t +T denote the t^{th} and $(t+T)^{th}$ time slots.

The modulator consists of an Inverse Fast Fourier Transform (IFFT) block. The output of the IFFT block after two time slots at each transmitter are OFDM symbols in discrete time domain and are given by

$$D_{p,k} = \frac{1}{M_0}\sum_{n=0}^{M_0-1} x_n^p(k)\, e^{i\frac{2\pi}{M_0}kn} \qquad p\,\epsilon\,[1, N_t] \tag{3}$$

After IFFT operation, a parallel to serial conversion is used and a Cyclic Prefix (CP) is added. In order to avoid OFDM Inter Symbol Interference (ISI), the CP is assumed to be longer than largest multipath delay spread. The resulted MIMO-OFDM symbol is transmitted over a frequency selective fading channel.

B. Channel

We assume that the MIMO-OFDM symbols are transmitted over a frequency selective Rayleigh and Rician fading channels. We also assume that the channel taps remain constant during transmission. We can represent the received signal as

$$r(t) = s(t) * h(t) + n(t) \tag{4}$$

where * represents Convolution and h(t) is the impulse response of the random channel and n(t) is Additive White Gaussian Noise (AWGN).

If there is no line-of-sight (LoS) component between transmitter and receiver, the constructive and destructive nature of multipath components can be approximated by Rayleigh distribution and hence the envelope of h(t) follows Rayleigh distribution. The probability distribution function (pdf) of Rayleigh distribution is given by

$$p(r) = \frac{r}{\sigma^2} e^{\frac{-r^2}{2\sigma^2}} \quad r \geq 0 \tag{5}$$

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where σ^2 is the average power of the received signal [15].

When there is a line-of-sight (LoS), direct path component gets added to multipath components. This type of signal can be approximated by Rician distribution and hence the envelope of h(t) follows Rician distribution. As the direct path component experience deeper fading, the signal characteristics goes from Rician to Rayleigh distribution. The probability distribution function (pdf) of Rician distribution is given by [17, (2.15)]

$$p(r) = \frac{(1+K)e^{-K}r}{\sigma^2} e^{\frac{-(1+K)r^2}{\sigma^2}} I_0\left(2r\sqrt{\frac{K(K+1)}{\sigma^2}}\right) \quad r \geq 0 \qquad (6)$$

where K is the specular-to-diffuse ratio of the received signal $I_0(\bullet)$ is the modified Bessel function of the first kind and zero-order.

We assume channel coefficients to be varying slowly such that they are almost constant over two transmission time instants. The channel frequency response of the k^{th} subcarrier is

$$H(k) = \sum_{p=1}^{l-1} h(\rho) e^{j\frac{2\pi k\rho}{n}} \qquad (7)$$

where h(ρ) is the complex channel gain of the ρ^{th} multipath component.

C. Receiver

At the receiver, after removing cyclic prefix (CP), we perform FFT operation. The signal at the output of FFT block can be expressed as

$$y_n^q(k) = \sum_{p=1}^{2} H_{qp}(k) x_n^p(k) + w_n^q(k) \quad q = 1,2 \qquad (8)$$

where $H_{qp}(k)$ is the subchannel gain from the p^{th} transmit antenna to the q^{th} receive antenna.

The obtained symbols $y_n^1(k)$ and $y_n^2(k)$ are sent to parallel to serial converter followed by Golden STBC decoder which is a brute force Maximum Likelihood (ML) decoder. Maximum Likelihood (ML) decoding is an optimum decoding technique which searches for a vector over all possible constellation points so as to minimize $||Y\text{-}HX||^2$, i.e., the ML decoder generates the estimate of the received vector as [12]

$$\hat{X} = argmin_{X\epsilon C}||Y - HX||^2 \qquad (9)$$

The decoder outputs the estimates of the Golden encoded symbols. These estimates are sent as inputs into QAM modulator which yields the final output.

IV. Simulation Results

To analyze the performance of Golden coded MIMO-OFDM systems over Rayleigh and Rician frequency selective fading channels, we consider total number of used subcarriers as 52 in which 48 are data carriers and 4 are pilot carriers. The pilot symbols [16] are used for the estimation of the channel. The FFT/IFFT length is chosen to be 64 and the length of cyclic prefix (CP) is 16.

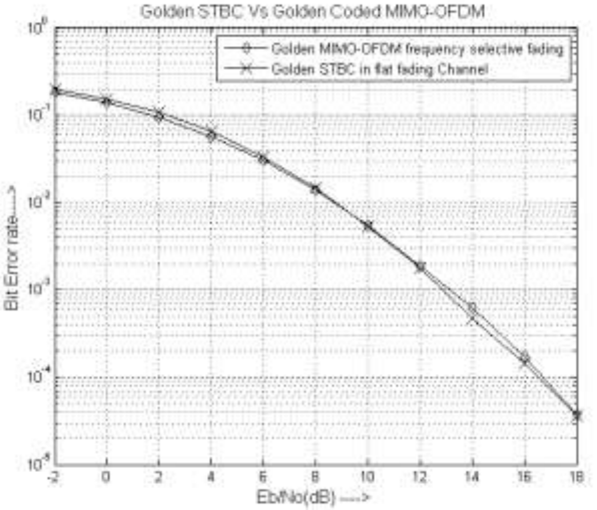

Fig. 2. Golden STBC (4-QAM) in Flat Fading Vs Golden Coded MIMO-OFDM (4-QAM) in Frequency Selective Rayleigh fading Channels.

OFDM systems in frequency selective Rayleigh fading channel with 2X2 Golden coded MIMO systems in Rayleigh flat fading channel and we observe that the two graphs coincide. It implies that the deployment of OFDM effectively combats the frequency selective conditions of the channel.

We analyze the performance of 2X2 Golden coded MIMO-OFDM systems in frequency selective Rician fading channels with different K factors. We observe that, the overall BER performance of the system improves with increase in K factor. The increase in K factor implies the increase in the power of dominant LoS signal which renders the improvement of BER performance of the system. As shown in the fig 3. When K value increases from 6 dB to 10 dB, the increase in overall system performance is 1.7 dB for a BER of 10^{-4}.

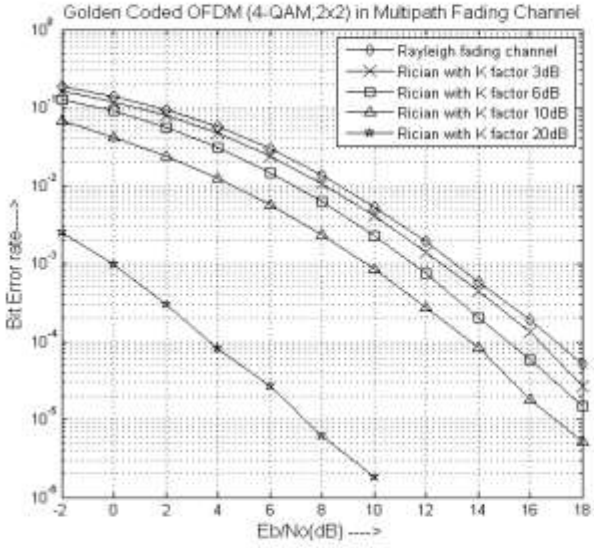

Fig. 3. Golden Coded MIMO-OFDM (4-QAM) in Frequency Selective Rician Fading Channels.

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channel and its performance is identical to that in fig 2.

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V. Conclusion

In the paper, we analyzed the performance of 2X2 Golden coded MIMO-OFDM system in Rayleigh and Rician frequency selective fading channels. The Golden code is an optimal Algebraic space-time code which exploits space and time dimensions. On the other hand, the OFDM technique exploits frequency dimension. Thus, by combining Golden STBC with OFDM, we achieve maximum diversity gain. We also show by simulations, as the strength of line-of-sight (LoS) component increases, the BER performance of the 2X2 Golden coded MIMO-OFDM system improves in frequency selective fading channels.

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