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# Interference Cancellation in Golden Coded MIMO-OFDM System

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**Abstract—***In this paper, mitigation of inter carrier interference (ICI) in golden coded multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system and improvement in its bit error rate (BER) performance is evaluated. The golden code is a full rate 2×2 optimal algebraic space time block code (STBC) which exploits time and space dimensions. On the other hand, MIMO-OFDM exploits the frequency dimension. Maximum diversity gain is achieved by combining golden STBC with MIMO-OFDM system. MIMO-OFDM systems suffer from ICI caused by carrier frequency offset and phase noise. Inter carrier interference self cancellation (ICI-SC) scheme is used to improve the BER performance of golden coded MIMO-OFDM system. From simulation results, it is shown that an improvement of 4 dB in signal to noise (SNR) is obtained for a symbol error rate of* $10^{-3}$.

## 1. INTRODUCTION

The next generation communication media demands high data rate, high performance and link reliability. The unique features of MIMO-OFDM systems meet all requirements of next generation communication media [1], [2]. In wireless networks, transmitted signal passes through different paths. Hence, there are multiple copies of one signal which are attenuated and delayed in time as well. For high data rate transmission media, this multipath effect make MIMO system frequency selective fading channel. These days OFDM is widely used for communication purpose since it can transform a frequency selective fading channel into a parallel flat fading channel. In OFDM systems, signals are modulated on different sub-carriers which are orthogonal to each other. Orthogonality means sub carriers do not interfere with each other which ensures the efficient utilization of the bandwidth.

Inter carrier interference (ICI) is one of the most common problem in OFDM systems [3]. This problem of ICI still exists in MIMO-OFDM system due to impairments of time varying channel and frequency offset (FO) of local oscillator at transmitter and receiver side [4], [5]. MIMO-OFDM systems are very sensitive to frequency offset because it degrades the performance of the system. In the presence of frequency offset, a very small disturbance in sub carrier will degrade the performance of MIMO-OFDM systems up to a great extend.

Now this problem of ICI can be mitigated by simply applying a self cancellation technique. The ICI-SC [6], [7] involves modulation of same data on adjacent sub carriers with opposite polarity. The data allocation scheme with this modulation can be shown as (X (k), X (K+1) = -X (k)), is called ICI self cancellation modulation. At the receiver side, the received signals are simply subtracted from signal on adjacent sub carrier and this scheme is called ICI self cancellation demodulation.

For broadband application, STBC are used to strengthen the performance of MIMO systems [8] by providing spatial multiplexing gain. Alamauti STBC [9] is one of the simplest space time block code in this category but it is a half rate data code. Further many other STBC are also designed to achieve maximum diversity gain in the channel. Full rate full diversity STBC, the golden code [10], was proposed in 2005. For 2×2 MIMO systems, golden STBC have maximum coding gain [11], [12]. In various applications of MIMO-OFDM systems, golden codes have been applied successfully. The BER performance of golden coded MIMO-OFDM system by reducing ICI has not been studied previously.

In this paper, we analyze the performance of golden coded MIMO-OFDM systems with ICI self cancellation technique. Furthermore we also compare the BER performance of golden coded MIMO-OFDM system with and without applying ICI-SC. It is shown that there is significant improvement in SNR because of reduction in ICI coefficients.

The rest of paper is organized as follows. Section II gives a brief idea about golden codes, section III describe golden coded MIMO OFDM system.

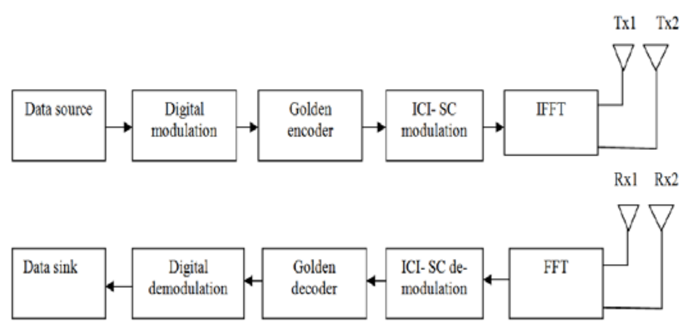


**Fig. 1: Golden coded MIMO-OFDM system**

ICI-SC in golden coded MIMO-OFDM system and simulation results are shown in section IV and V respectively. Finally the last section concludes the paper.

## 2. GOLDEN CODES

The golden code was first proposed in [10] as an optimum linear dispersion space time block codes for a 2×2 MIMO systems. These codes are constructed from a particular family of division algebras named as cyclic division algebras. These codes are named golden codes because of the role of golden number $\frac{1+\sqrt{5}}{2}$ in its construction. The Golden codes matrix is

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

where a,b,c and d are the information symbols taken from any signal constellation and $i=\sqrt{-1}$, $\theta=\frac{1+\sqrt{5}}{2}=1.618$ (golden number), $\sigma(\theta)=\frac{1-\sqrt{5}}{2}=1-\theta$, $\alpha=1+i-i\,\theta=1+i\,\sigma(\theta), \sigma(\alpha)=1+i-i\,\sigma(\theta)=1+i\,\theta.$

Golden codes satisfy non vanishing determinant (NVD) property [13] which implies that minimum determinant must be constant regardless of the signal constellation size. The minimum determinant of golden code is

$$\delta_{min}=\min_{X\neq 0}\left(|\det(X)|^2=\frac{1}{5}\right). \quad (2)$$

## 3. GOLDEN CODED MIMO-OFDM SYSTEM

Let us consider a system with two transmitting antennas and two receiving antennas [14] which transmit and receive signal over a frequency selective MIMO channel using OFDM modulation scheme per antenna. As shown in Fig. 1 all binary data sequence is generated at once and then modulated using quadrature amplitude modulation (QAM). The modulated data stream is then passed through a golden space time block code encoder. The STBC encoder convert the high speed data stream $d_k$ into four sub streams $d_k^{(i)}$for [i=1,2,3,4] and transmitted through different transmitting antennas in different time slots. A simple two branch transmitter diversity scheme to explain the diversity gain of STBC over frequency selective fading channel is considered here. The data symbols to be transmitted are distributed over two antennas and M is the number of sub carriers in OFDM modulator. The $m^{th}$ data block to be transmitted through antenna tx1 in first time slot 1 is given by

$$G^1=\alpha(a_{m,k}+b_{m,k}\theta) \quad (3)$$

where $a_{m,k}$ and $b_{m,k}$ represent the $k^{th}$ data symbol in $m^{th}$ block to be transmitted. In the same way, signal at transmitter 2 in first time slot is given as

$$G^2=i\sigma(\alpha)\big(c_{m,k}+d_{m,k}\sigma(\theta)\big) \quad (4)$$

In second time slot, signal at transmitter 1 and 2 is given as respectively

$$G^3=\alpha\big(c_{m,k}+d_{m,k}\theta\big) \quad (5)$$

$$G^4=\sigma(\alpha)(a_{m,k}+b_{m,k}\sigma(\theta)) \quad (6)$$

The signals at the transmitting antennas can be represented by

$$g_n^1=[\alpha\big(a_{m,k}+b_{m,k}\theta\big)\;\alpha\big(c_{m,k}+d_{m,k}\theta\big)] \quad (7)$$

$$g_n^2=[i\sigma(\alpha)\Big(c_{m,k}+d_{m,k}\sigma(\theta)\Big)\;\sigma(\alpha)(a_{m,k}+\quad b_{m,k}\sigma(\theta))] \quad (8)$$

where $g_n^1$ and $g_n^2$ represent the golden coded symbols transmitted from transmitter 1 and transmitter 2 in time slot $t1$ and $t2$ respectively. For sake of simplicity, we can rewrite the golden code transmission matrix as

$$g=\begin{bmatrix}G^1 & G^3\\ G^2 & G^4\end{bmatrix} \quad (9)$$

In OFDM modulator section, data symbols are modulated on the bins of inverse fast frequency transpose (IFFT) since bins of IFFT are orthogonal to each other. The output of IFFT block in discrete time domain can be given as

$$G_{p,k}=\frac{1}{M}\sum_{n=0}^{M-1}g_n^p(k)e^{i\frac{2\pi}{M}kn}\;\; p=1,2 \quad (10)$$

where $g_{p,k}$ represent the OFDM symbol modulated on $k^{th}$ subcarrier at $p^{th}$ transmitting antenna and M is the size of IFFT block. Before transmitting OFDM signal in the channel, a cyclic prefix (CP) of adequate length is also added to the OFDM symbol in order to avoid inter symbol interference (ISI). The length of CP should be longer than the largest multipath delay spread.

The signal passing through the channel can be represented in time domain as

$$y(t)=d(t)*h(t)+w(t) \quad (11)$$

where y(t) represent the signal received at the receiver, h(t) give the impulse response of the channel and w(t) is the additive white Gaussian noise (AWGN). At the receiver side, received signal is passed through FFT block which perform the inverse operation of IFFT. The output of IFFT block is given as

$$y_n^q(k)=\sum_{p=1}^{2}H_{qp}(k)g_n^p(k)+w_n^q(k)\;\; q=1,2 \quad (12)$$

where $H_{qp}(k)$ is the sub channel gain from $p^{th}$ transmitting antenna to $q^{th}$ receiving antenna.

The resultant signal is passed through the golden code decoder which is basically a maximum likelihood (ML) detector. The ML decoder finds out a vector over all possible points of constellation so as to minimize the euclidean distance$\|Y-HD2$. The estimate of the received vector is generated by ML decoder and given as

$$\hat{G} = argmin\ \|Y - HG\|^2 \quad (13)$$

This estimated signal is passed to the digital demodulator which results into estimated output binary sequence.

## 4. INTERFERENCE CANCELLATION

Since MIMO-OFDM systems also suffer from the problem of ICI which was induced due to frequency mismatch of local oscillator of transmitter and receiver, synchronization error and Doppler spread. This FO destroys the orthogonality of OFDM signals and degrades the system performance. One of the simplest techniques to mitigate ICI in OFDM systems is ICI-SC which was proposed by Zhao and Haggman [6].

### 4.1. ICI self cancellation modulation

With this modulation technique, the main idea is to transmit the same data two times with same amplitude but with opposite polarization on the adjacent subcarriers. The golden coded MIMO-OFDM signal with ICI self cancellation modulation is given as

$$X(1)^p = -X(0)^p, X(3)^p = -X(2)^p \dots X(M-1)^p = -X(M-2)^p \ p = 1,2 \quad (14)$$

With this modulation scheme coefficient of ICI signal reduced and this is called ICI-SC modulation.

### 4.2. ICI self cancellation demodulation

The demodulation scheme is supposed to work in such a way that received signal on a subcarriers is summed with signal at adjacent sub carrier with opposite polarity. The golden coded MIMO-OFDM signal with ICI self cancellation demodulation is given as

$$Y'(k)^q = Y(k)^q - Y(k+1)^q \ q = 1,2 \quad (15)$$

The amplitude of ICI coefficients is further reduced by this demodulation scheme. The combined modulation and demodulation scheme is called ICI self cancellation scheme.

## 5. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

To analyze the system performance ICI self cancellation scheme over golden coded MIMO-OFDM system, the modulation scheme considered is QAM. We observed that overall BER performance of 2×2 golden coded MIMO-OFDM system improved by applying ICI-SC technique. For same level of BER an improvement of 3 to 4 dB in signal to noise ratio has been obtained.

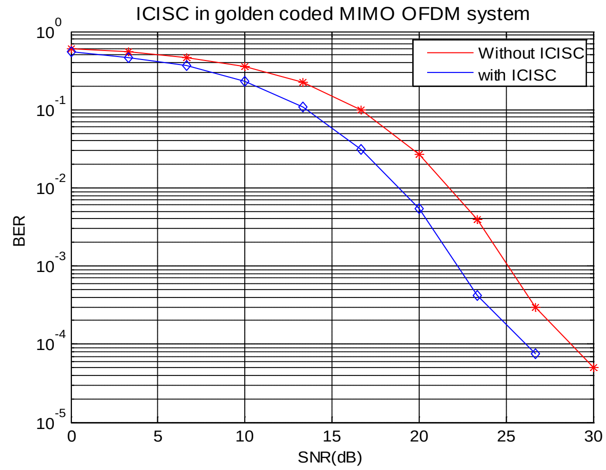


**Fig. 2: BER performance of golden coded MIMO-OFDM system with ICI-SC.**

## 6. CONCLUSION

The combining scheme of golden coded MIMO-OFDM systems and ICI-SC technique is studied. This combining scheme provides a significant improvement in BER performance as shown by simulation results. This scheme can also be applied to other full rate full diversity space time block coded MIMO-OFDM systems. There is no increase in system complexity since proposed scheme is quite simple to implement.

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