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A Channel independent precoding with different equalization techniques in a MIMO based system

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ABSTRACT

MIMO systems are used in wireless communication where the capacity of the radio link can be increased by using multiple transceivers to support the multipath propagation. The interferences occurring between the different antenna elements in MIMO OFDM can be mitigated by using the precoding technique, where the data is coded and transmitted to reduce the bit error rate. In this paper, a channel independent precoding technique with interference alignment concept is considered to mitigate the interference in the system. To recover this precoded data, different equalizers like Zero Forcing equalizers, MMSE equalizers etc. are used in the receiver section. The simulation results shown that the precoding with MMSE equalizers at the receivers can outperform precoding with the Zero forcing detectors.

Keywords: Equalizers; MIMO; MMSE; OFDM; precoding; zero forcing

1. INTRODUCTION

In a wireless communication system, reliable transmission of the data is an important factor. To achieve a reliable transmission, it is essential to transmit the data with low interferences. Achieving high data rate, spectral efficiency, capacity and throughput are also inevitable. To satisfy all the above needs in the fields of the cellular technology is difficult, since the bandwidth availability is limited. To mitigate these situations new emerging techniques like MIMO systems can be considered (Cassio, 2008). The MIMO systems can use multiple number of antennas at both the transmitter side and the receiver side to increase the data rate of the system. It has been deployed in the areas where different users can access a single base station. This is termed as the Multi-User MIMO systems (Clark, 1998). The base stations should coordinate the transmission through the different antenna elements here (Falconer, 2002). But as the signal propagates it undergoes certain interferences and receiver section will become unable to coordinate the signal properly (Grossmann, 2006). The Orthogonal Frequency Division Multiplexing (OFDM) is an efficient modulation technique which gains most popularity in obtaining high speed and better data transmission over the multipath fading situations (Jin Wang, 2012). So the MIMO-OFDM can be introduced to enhance the error performance and channel capacity of a communication system.

In conventional OFDM systems, cyclic prefix are added between the symbols to avoid the inter symbol interferences occurring in the system (Martin Haardt, 2007). The cyclic prefix length is designed to be not more than the channel impulse response to eliminate the inter block interferences occurring (Mesleh, 2008). Hence, a long cyclic prefix is employed to eliminate the interference effects when the multipath delay spread is more. But if the cyclic prefix length is increased beyond a particular limit, it can affect the spectral efficiency of the channel. Because of the limited bandwidth availability, it reduces the capacity of the channel. Generally, by using the MIMO systems instead of SISO, the capacity can be increased considerably by increasing the data rate. In order to improve transmission efficiency further precoding techniques can be used at the transmitter section.

Precoding is the generalization of the beamforming technique which can be used in the MIMO systems to support the multi-layer transmission in wireless communication system. It allows a joint processing of all the incoming data to improve the overall performance of the system (Mietner, 2011). All the transmitted data are been weighted by a factor depending upon the channel conditions here (Ohno, 2005). Each of the antenna port will contain at least some portions of data from all the layers. The same data is transmitted from each of the multiple antennas with appropriate weighing and signal power is maximized in conventional beamforming (Ohno, 2006). In precoding, different data streams are transmitted from different antennas with independent and appropriate weighing such that the throughput is maximized at the receiver output. Precoding can be classified as linear precoding and nonlinear precoding (Park, 2004). The linear precoding algorithms transmit the data in a linear manner and they are having much lower complexity also (Ping Yang, 2011). The nonlinear precoding systems are complex but comparatively it can achieve more capacity (Quentin, 2016).

In this paper, a channel independent precoding with the interference alignment concept is considered for eliminating the interference occurring in the system (Randall T. Becker, 2009). The interference in the current OFDM block can be eliminated by knowing the interference in the previous OFDM block. The concept of interference nulling is to align the interference in one subspace and it should be disjoint from the signal space (Sun X, 2002). Here the interference subspace dimension should be kept as minimum as possible and probably it should have a dimension of half of the difference between the channel impulse response length and the cyclic prefix length (Tepedelenlioglu, 2003). At the receiver section these separately aligned interferences can be removed by using the operators like zero forcing operators. Instead of using the zero forcing detectors, MMSE (Minimum Mean Square Error) equalizers can be considered to enhance the performance of the system (Trautmann and Fliege, 2008).

System model: The MIMO OFDM model for a wireless communication system is given in this section. Multiple number of antennas are used at the transmitter section and receiver section to increase the data rate and capacity of the system.

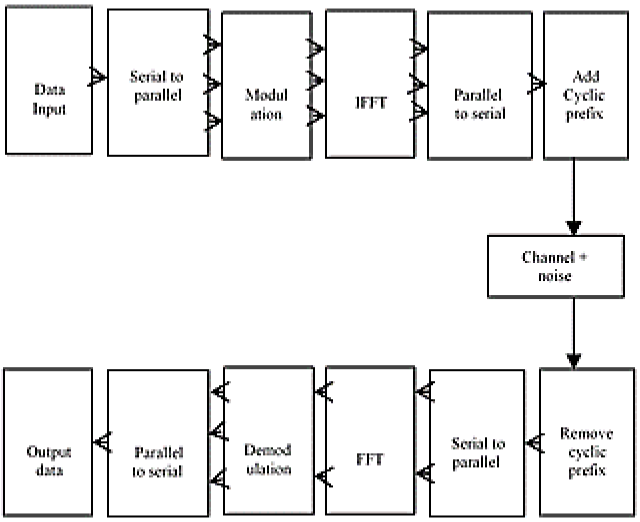

Fig.1.MIMO OFDM system

The data to be transmitted is first taken to a serial to parallel converter where the data in serial format is converted to a parallel manner. This is done because, when the bandwidth of a signal to be transmitted is greater than the coherence bandwidth of the channel the frequency selective fading may occur. To avoid this situation the signal bandwidth are divided in parallel manner. The incoming data is now digitally modulated by using the QAM, BPSK, QPSK etc. like modulation methods. The digitally modulated data is then transmitted to the Inverse Fourier Transform block. It is used to convert the signals in frequency domain format into the time domain signals. Then the cyclic prefix is added between the symbols to avoid the inter symbol interference (ISI). Data is then transmitted serially through the AWGN or Rayleigh channels. At the receiver side, all the cyclic prefix added in transmitter side are eliminated and Fourier transform is done to obtain the frequency domain signals for easy transmission. Then the demodulation is performed and the output data is obtained at the receiver end.

3. Channel independent precoding: Precoding methods can be grouped into three based on the dependency on the channel state information: Precoding with full CSI, precoding with limited CSI and precoding with no CSI. By properly designing the transceiver section and multi-access orthogonal schemes, we can achieve better performance through the channel independent precoding.

The basic concept of interference alignment or nulling based channel independent precoding is to align the interference subspace separately from the signal subspace and thus eliminate the total interference occurring in the system. The dimension of interference subspace should be as small as possible and signal subspace dimension should me more. For that a precoding matrix has to be designed so that the total IBI in the system can be eliminated properly. Along with that, an insufficient cyclic prefix condition to increase the spectral efficiency of the system is also considered.

Consider a MIMO OFDM system with number of subcarriers as N. Let x_k be the input data and p be the precoding matrix that has been designed. Hence the precoding output is given as,

$$r_k = p * x_k \tag{1}$$

where r_k is the input vector to the k^th OFDM block. The IFFT operation is performed on the precoded data and they are transmitted across the channel. Certain IBI and ICI component matrices are also defined while designing the precoder. While passing through the channel, Gaussian noise also gets added. Hence the input to the receiver end is now given as

$$y_k = (C - S) W_N r_k + I\, W_N r_{k-1} + n_k \tag{2}$$

where C is a circulant matrix, W_N is the IDFT matrix, S and I are the N * N ICI and IBI component respectively.

$$C = \begin{bmatrix} 0_{(L-V)\times(N-L+V)} & S & 0_{(L-V)\times V} \\ . & & \\ 0_{(N-L+V)\times(N-L)} & 0_{(N-L+V)\times(L-V)} & 0_{(N-L+V)\times V} \end{bmatrix} \tag{3}$$

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$$I = \begin{bmatrix} 0_{(L-V)\times(N-L+V)} & S \\ 0_{(N-L+V)\times(N-L+V)} & 0_{(N-L+V)\times(L=V)} \end{bmatrix} \qquad (4)$$

$$S = \begin{bmatrix} h(L) & h(L-1) & h(V+1) \\ 0 & h(L) & h(V+2) \\ 0 & 0 & h(L) \end{bmatrix} \qquad (5)$$

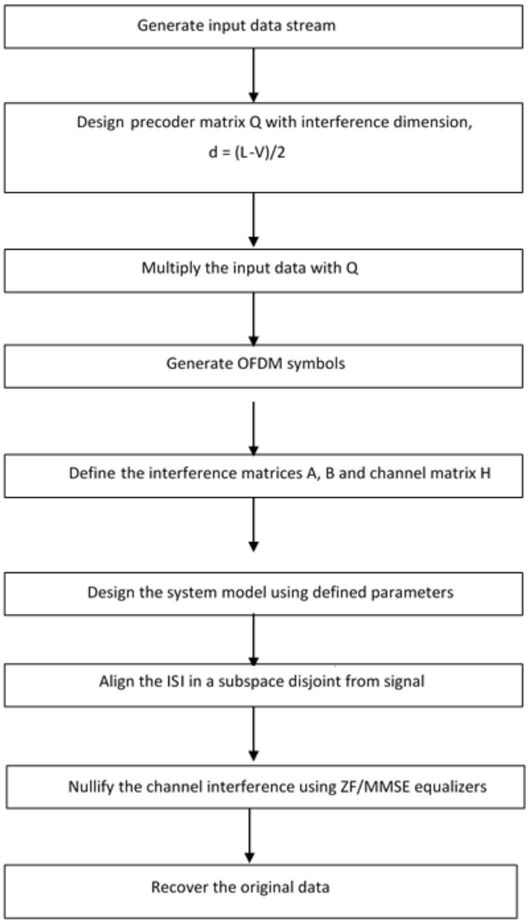

Fig.2.Flowchart showing channel independent precoding

Here the interference subspace dimension is given as,

$$D = (L - V)/2 \qquad (6)$$

where L is the length of CIR or delay spread and V is the cyclic prefix length. D should be minimum as possible.

Consider the precoding matrix be a matrix of size 64 x 64 with V = 12 and L = 16. Hence the precoding matrix is given by,

$$p = \left[e_{61}\, e_{62}\, e_1 \,..........e_{60} \;\; 0\, 0 \right] \qquad (7)$$

where $e_i = [0\ldots\ldots 0, 1, 0\ldots\ldots\ldots 0]^T$ which is a 64 x 1 orthonormal vectors.

Equalizers for interference cancellation: In order to achieve better capacity and BER performance of the system, it is inevitable to eliminate the interferences at the receiver section. Equalizers can be used to reduce the interferences occur in the system during the signal transmission through the channel. Different types of equalizers like Zero forcing equalizers, MMSE equalizers or the Maximum likelihood equalizers can be used for this.

Zero Forcing Equalizer: Zero forcing equalizer is a type of linear equalizer, which can process the incoming data with a linear filter. It approximates the inverse of the channel with a linear filter. That means, it consider the inverse of the channel frequency response. This inverse of the channel frequency response at the receiver is used to restore the signal. Let F (f) be the frequency response of the channel and C (f) be the zero forcing equalizer response. Then frequency response is the inverse equalizer response and this brings down the interference to zero in a channel.

Consider a 2x2 MIMO system with independent and time varying Rayleigh channel between the source and receiver. Let the transmitted sequence be $(x_1 \; x_2 \; ....x_n)$. Hence, during the first time slot x_1 and x_2 are send and during the second time slot x_3 and x_4.

The received signal from first antenna in the first time slot is,

$$y_1 = h_{1,1}x_1 + h_{1,2} \; x_2 + n_1 = \begin{bmatrix} h_{1,1} & h_{1,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \qquad (8)$$

For the first time slot the received signal on second antenna is,

$$y_2 = h_{2,1}x_1 + h_{2,2} \; x_2 + n_2 = \begin{bmatrix} h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \qquad (9)$$

where $h_{1,1}, h_{1,2}, h_{2,1}$ and $h_{2,2}$ are the channel matrices from each of the corresponding transmitter antenna to the receiver antenna.

Therefore the received signal is given as,

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \qquad (10)$$

Equivalently it is rewritten as,

$$y = Hx + n \qquad (11)$$

To find the x value here, a weighing matrix W has to be considered such that, $W * H = I$ (Identity matrix),

$$W = (H^H H)^{-1} H^H \qquad (12)$$

This W is also known as the pseudo inverse for a matrix. The ZF equalizers always tries to cancel out the interference term as the off diagonal elements of H^H are not zero. When x_1 is solved then the interference from the x_2 term can be eliminated and vice versa. But the problem with the zero forcing equalizers is that, for some frequencies the transmitted and received signal may be weak. Hence to obtain that the gain of the ZF equalizer has to be large and this can further lead to the amplification of noise. Also there are some cases where the frequency response of the channel is zero and hence it cannot be inverted. As a solution for this the MMSE equalizers can be considered.

MMSE Equalizer: MMSE equalizer is also a linear type equalizers which are used to minimize the E $[|e|^2]$, where e is the error signal. The difference in value between the signal transmitted and the signal obtained at the output gives the error signal. For the MMSE equalizer, the frequency response of the channel and the response of the equalizer are related as follows,

$$C(f) = \frac{1}{F(f) + k} \qquad (13)$$

where k is the channel response and signal to noise ratio. Generally, the MMSE do not eliminate the ISI completely. Instead of that it will minimize the noise power completely from the signal obtained. Consider the input sequence as $(x_1 \; x_2 \; ....x_n)$. The MMSE receiver always use a co-efficient W to minimize the error in the system given below,

$$E\left\{ (Wy - x)(Wy - x)^H \right\} \qquad (14)$$

Here the co-efficient W is given by,

$$W = (H^H H + N_0 I)^{-1} H^H \qquad (15)$$

The N_0 term refers to the noise occurring in the system. When noise term is neglected then the MMSE equalizer will turned into a zero forcing equalizer.

Performance analysis: The performance of the channel independent precoding based on the interference alignment can be evaluated by plotting a BER versus SNR curve. Generally the BER plot can be considered as a key parameter in analysing the transmission of the digital data along the communication channel. BER can be defined as ratio of number of errors occurred in a system to the total number of data bits transmitted. If the channel through which data is transmitted is interference free, then the signal to noise ratio is better and the BER will be small. For a good communication system always the error rate should be minimum. If error is more, the integrity of the system is reduced. The BER versus SNR plot for the different equalizers can be plotted to evaluate their performance also. Here the precoding in the MIMO systems are considered rather than the SISO systems as the data rate and capacity is more for MIMO. The channel capacity can be enhanced by increasing the number of transmit and receive antennas and thereby improving the data rate of the system.

Simulation results: The simulation results for the channel independent precoding in MIMO OFDM systems are presented in this section. The plot between the BER and signal to noise ratio are shown here to evaluate the performance of the zero forcing equalizers, MMSE equalizers and ML detectors. The capacity improvement for a communication channel, with the increase in the transceiver antennas are analysed by considering a capacity plot also. Fig. 3 illustrates the capacity plot for SISO and MIMO systems with different antenna elements.

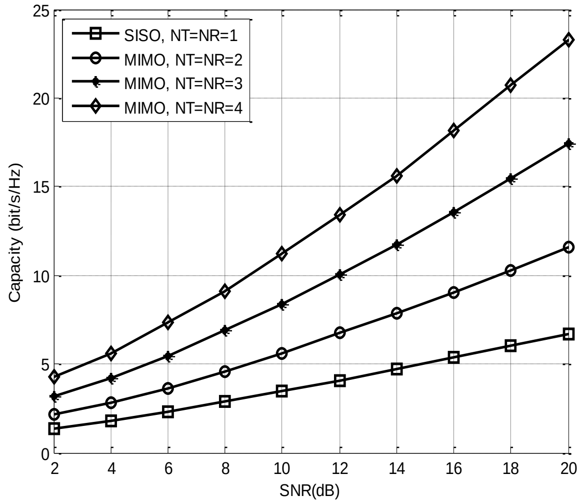

Fig. 3. Capacity plot for MIMO with different antenna elements

The capacity is been plotted based on the Shannon capacity formulae. When the number of antennas increases, the capacity of the system is enhanced. For a SISO system, only one symbol is transmitted at a time slot. But if the MIMO systems are considered, for 2x2 MIMO symbols are grouped into two and at each time slot two symbols are transmitted and so on. Thus the data rate is doubled and the capacity is increased. So when the number of transceiver antenna increases the data rate and capacity increases.

Fig. 4 shows the error performance of the unprecoded and precoded MIMO with different cyclic prefix length. The delay spread length is taken as 17 and CP length as 16 and 12 so that the interference dimension will be limited to 2. Results shows that as the cyclic prefix length decreases the BER performance degrades.

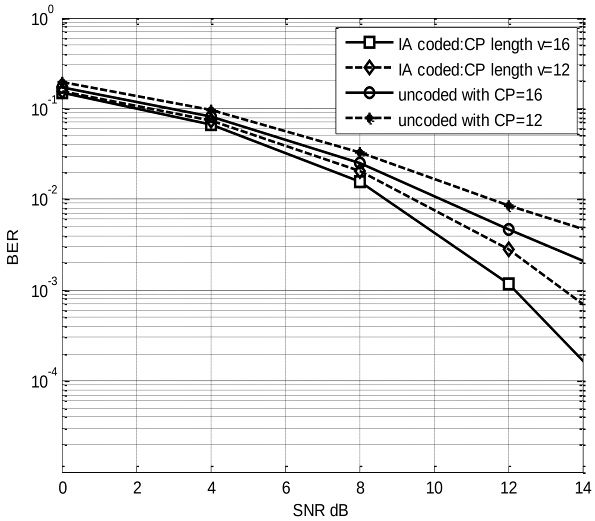

Fig. 4. BER performance of Channel independent precoding with different CP length

Table.1.Simulation Parameters

Simulation Parameters	Value
Transmit antenna	2
Receiver antenna	2
Data length	10^5
FFT size	256
Modulation	QAM
Cyclic prefix length	16
Precoding matrix size	64 x 64

Table.1.shows the parameters used in simulation. The data of length 10^5 is transmitted over the MIMO OFDM system with 64 subcarriers. The modulation technique used is QAM and a precoding matrix of 64x64 dimension is used for doing the channel independent precoding. In Fig. 5 the Zero Forcing equalizer in the channel independent precoders is given. A flat fading Rayleigh channel is considered for transmission. An input data of 10^5 length is transmitted

over the 2x2 MIMO OFDM system with QAM modulation. For ZF equalizer, a pseudoinverse operation is performed and the input data is equalized.

The BER performance of the ZF and MMSE equalizers are compared in Fig. 6. Consider a flat fading Rayleigh channel where only one tap is considered in the multipath channel. MMSE equalizers can reduce the average error occurring in the system. Results shows that the MMSE equalizers can yield better BER performance than the ZF equalizers.

For a frequency selective fading channel, the interferences can occur when signal is transmitted from one end to other. In channel independent precoding the interferences are aligned separately from the signal subspace and they are transmitted to the receiver section. At receiver end the equalizers can be used to cancel out these interferences.

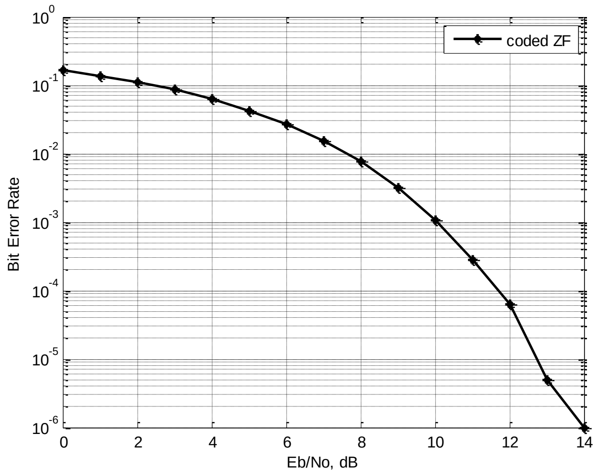

Fig.5.BER vs SNR plot for ZF equalizer in precoder with flat fading channel

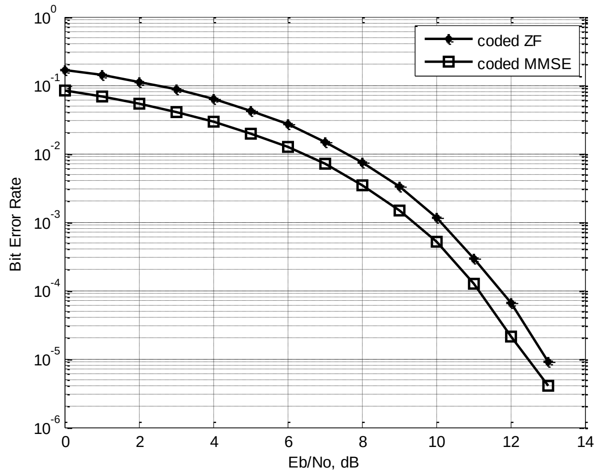

Fig.6.Comparison of the coded ZF and MMSE equalizers in frequency selective Rayleigh channel

2. CONCLUSION

Precoding is used to eliminate the interferences in the communication system by the joint processing of the incoming data. In this paper, a channel independent precoding based on the interference alignment method is considered. The signal subspace is made disjoint from the interference subspace and at receiver section this interference is eliminated by using the zero forcing like equalizers. Also the interference subspace dimension should be as minimum as possible. Further improvement in the BER performance can be obtained by using the equalizers like MMSE equalizers at the receivers. The simulation results shows that the MMSE equalizers in receiver section along with the interference cancellation can outperform the ZF equalizers.

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