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Performance Analysis of Linear and Nonlinear Precoding in MIMO Systems

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Abstract: A MIMO system which is used to achieve high data rate and capacity in transmission medium is one of the significant emerging technologies today. The interferences occurring between the different antenna elements in MIMO OFDM can be mitigated to improve the performance of the system. The precoding technique, where the data is coded and transmitted to reduce the bit error rate can be used for this. There are linear precoding and nonlinear precoding methods are there.Linear precoding schemes have low complexity and can achieve a reasonable capacity. The nonlinear precoding can access more capacity with much receiver complexity. In this paper, the BER performance of different precoding schemes like Channel Inversion, Block Diagonalization, DPC and TH precoding are analysed to get a better performance for the MIMO systems. Simulation results shows that the nonlinear precoding technique Dirty Paper Coding (DPC) achieves better performance than all other precoding methods.

Keywords: BER, DPC, MIMO, OFDM, Precoding.

I. INTRODUCTION

In the communication field the numbers of users are increasing day by day. Hence the need for achieving better spectral efficiency, high data rate and high throughput with low latency in the transmission medium is a very challenging task. Since the spectrum is limited, to satisfy all the above needs in the fields of the cellular technologies are difficult [1]. To mitigate this situation new emerging techniques like MIMO systems can be considered. This Multiple Input Multiple Output (MIMO) technique which uses the multiple antennas at both the transmitter and the receiver section is considered as one of the major research area nowadays. 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. The base stations should coordinate the transmission through the different antenna elements here [3]. But as the signal propagates it undergoes certain interferences and receiver section will become unable to coordinate the signal properly. 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. So the MIMO-OFDM can be employed to improve the error performance and channel capacity of the system.

As the incoming data is been transmitted through the multiple antennas in the MIMO system there is always a possibility of occurrence of interference. In order to reduce the error incurred during the transmissions the MIMO uses proper pre-coding technique at the transmitter section. Precoding is the generalization of the beamforming technique which can beused in the MIMO systems to support the multi-layer transmission in wireless communication [5]. It allows a joint processing of all the incoming data to improve the performance of the system. All the transmitted data are been weighted by a factor depending upon the channel conditions here. Each of the antenna port will contain at least some portions of data from all the layers [4]. The same data is transmitted from each of the multiple antennas with appropriate weighing and signal power is maximized in conventional beamforming. 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. The linear precoding algorithms transmit the data in linearly and they are having much lower complexity and good performance. The nonlinear precoding are complex but can achieve more capacity comparatively [2].

In this paper certain linear precoding and nonlinear precoding techniques are been analyzed. Channel inversion (CI) is linear precoding technique which impose the constraint that all the interference terms as zeros. It is suitable for high power and low noise conditions. The Block Diagonalization (BD) precoding can avoid the interference between different users in a multi antenna scheme. The nonlinear coding like Dirty Paper Coding (DPC) cancels the interference caused by the previous block for the current transmission and combination of DPC with symmetric modulo operation is the Tomlinson-Harashima (TH) precoding.

II. SYSTEM MODEL

The MIMO OFDM model for the system is given in this section. MIMO uses multiple antennas at both the transmitter to transmit the data and it is received by using multiple receiving antennas.

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The serial data coming has to be converted into a parallel format before transmission. This is because as the signal bandwidth is greater than the coherence bandwidth then the frequency selective fading may occur [3]. To avoid this situation the signal bandwidth are divided in parallel manner.

This incoming parallel data is then digitally modulated by using either QAM, QPSK, BPSK like modulation schemes. The digitally modulated data is then transmitted to the Inverse Fourier Transform block [8]. It is used to convert the frequency domain signals into time domain signals. Then the cyclic prefix is added to avoid the inter symbol interference occurring between the symbols.

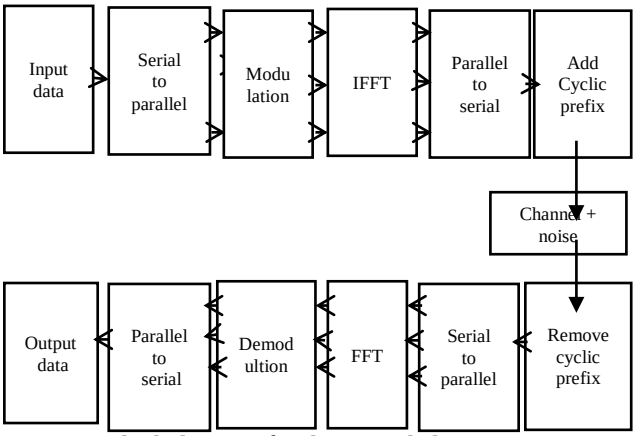

Fig 1. Block diagram for the precoded MIMO OFDM system

Data is the transmitted serially through the channels. At the receiver section the cyclic prefix is removed and Fourier transform is performed to obtain the frequency domain signals [10]. The demodulation is performed and the output data is obtained at the receiver end.

III.DIFFERENT PRECODING TECHNIQUES

If the interference cancellation is not done properly, the desired output is not obtained at the receiver. Hence precoding techniques are used to coordinate the transmission of data. Different such precoding techniques are discussed here.

A. Channel Inversion Precoding

Channel inversion precoding is a linear precoding technique where the interference occurs in the transmitted signal can be mitigated by considering all the interference terms as zeros. Channel inversions generally have the same processing as that of ZF equalization.

Let x be data input. In CI, the input data is precoded with the pseudoinverse ofchannel matrix H^{-1}. From the transmitter this precoded data is then given to the channel and there the columns of the pseudoinverse of the channel matrix are weighted properly to get different SNR values. Let w be the weight matrix used, then the received signal is o = x+ w. The signal having high SNR is chosen at the receiver end [3]. In multi user case ZF channel inversion precoding and MMSE channel inversion precoding are generally used.

Zero forcing channel inversion technique is a direct CI technique where independent sub channels are created for each user [6]. So the transmit power can be adjusted and the desired signal can be obtained. In certain CI method a small interference which is allowable is introduced in the system so that a large set of the output solutions can be obtained and from that better output is considered. This type of precoding is the Regularised CI precoding [8]. If the transmit power of one user is changed then the interference to all other users also varies. So by controlling the transmit power the capacity of the system can be improved. Another way is to keep the transmit power fixed and choose the proper precoding technique.This precoding technique can provide better performance in high power and low noise conditions. But as the inverse of channel matrix is taken in precoding section high values of normalising factors are needed.

B. Block Diagonalization

Block Diagonalization (BD) is a linear precoding technique used at transmitter side of MIMO systems to achieve maximum diversity gain. During signal transmission all the users other than the intended users are considered as the interference for that particular user [9]. This induced interference can be eliminated using the precoding method. In multi user case with different antenna elements even though the interference occurring are mitigated by CI precoding, the noise enhancement will be more. Block Diagonalization can be used to eliminate the inter user interferences between users but not between the different antenna elements. In BD precoding matrix is designed such that it should be in the null space of all other user's channel matrix [10]. The null space of the channel matrix H can be obtained by doing the SVD operation. Two SVD operations are used to:

- Generate the null space of channel matrix and precoding vector.
- To decompose channels into sub channels for optimal power allocation.

The computational cost is comparatively less for BD but error performance is not better as additional signal detectiontechniques are needed to eliminate the interference between different antenna elements. Detectors like zero forcing detectors, MMSE equalizers, Maximum Likelihood detectors etc. are considered in such cases.

C. Dirty Paper Coding and TH precoding

DPC is a nonlinear precoding technique which can be used when the channel state information is known to the transmitter side. Here the interference already known to the transmitter is eliminated and an interference free output can be obtained. For an n^{th} user, the interference caused by the (n-1) users is eliminated. The concept of DPC is that if the interference is known, then the capacity of a system is same as the capacity of a system when there is no interference [5]. QR decomposition is used here. Let P be theunitary precoding matrix and R be a lower triangular matrix, then the channel matrix is given by H=R*P.

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DPC along with a modulo operation is the vector precoding technique. To make the transmit power minimum the desired signal d is offset by the integer values of l so that the input to channel after precoding is $x = H^{-1}(d + \square\square l)$. For an n^{th} user the received signal is given as $y = d_n + \square\square l_n + w_n$. At the receiver a modulo operation is further performed to remove the effect of integer values of l [7].

Tomlinson-Harashima precoding is the combination of the DPC coding with the symmetric modulo operation and can be used to reduce the average power in decision feedback equalizer used in receiver side. Channel gain should be known at the transmitter for this. By knowing the previously transmitted symbols the post cursor interference can be eliminated.

IV. SIMULATION RESULTS

The simulation results for the various precoding in MIMO OFDM systems are presented in this section. The plot between the BER and signal to noise ratio are simulated here to evaluate the performance of all precoders discussed yet.

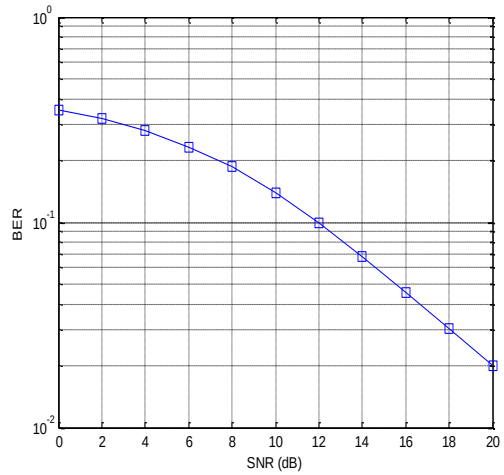

Fig 2. BER vs SNR performance of channel inversion precoding

In Fig. 2, the error rate performance of channel inversion precoder in the MIMO OFDM system is depicted. Let 200 packets of data are been transmitted in 10 frames here.

The modulation scheme used is QAM. To eliminate the interference the CI impose the constraint as all interference terms as zeros. From the graph, the error rate versus SNR curve of CI can be analysed.

Fig. 3, shows the BER performance of BD in MIMO system with 2 antenna elements at both transmitter and receiver. A zero forcing detector has to be used at the receiver to eliminate the interference occurring.

The BD precoding can give better performance than the CI at high SNR values.

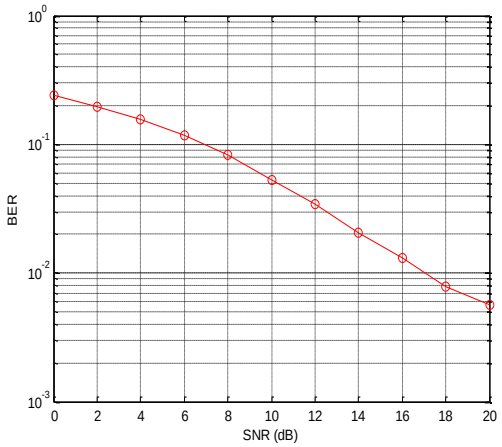

Fig 3. BER performance of Block Diagonalization precoding

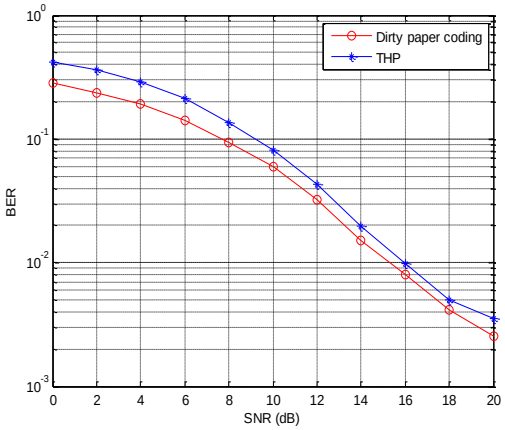

Fig 4. BER vs SNR plot of DPC and THP

In Fig. 4, BER curve for the DPC and THP is given. Herealso 200 packets of data are transmitted in 10 frames and error plot is obtained. From the graph it is shown that the DPC outperforms THP.

Even though the transmitted power for THP is less than DPC, THP have to do the symmetric modulo operation for precoding process. Hence its performance degrades.

Fig. 5 yields the comparison of the BER performance of CI, DPC and THP precoding. From the simulation results, it is observed that the non-linear precoding systems can achieve better performance than the linear precoding systems.

Among the non-linear precoding systems theDirty Paper Coding outperforms the Tomlinson Harashima precoding where the channel state information is also taken into account.

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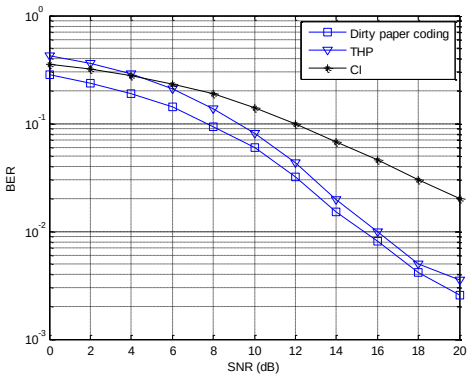

Fig 5. Comparison between the BER performance of CI, DPC and THP

V. CONCLUSION

Achieving high data rate, capacity, spectral efficiency etc. with low bit error rate and interferences is a challenging issue in the communication field. Precoding is used to eliminate the interferences in the communication system by the joint processing of the incoming data. In this paper, different precoding techniques in MIMO system were considered and their error performance was evaluated. Linear precoding techniques like BD have better performance than CI precoding. In case of nonlinear precoding, DPC outperforms THP because there is no modulo operation in DPC method.

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