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RESEARCH ARTICLE

Performance of Pre-Coded Spatially Multiplexed MIMO OFDM System

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Abstract*— Wireless communication systems suffer from fading and signal attenuation due to the mobility factor associated with it. OFDM (Orthogonal Frequency Division Multiplexing) is a multicarrier technique that offers high spectral efficiency. MIMO (Multiple Input Multiple Output) configuration provides enhanced capacity with the same transmit power. OFDM combined with MIMO offers increased diversity gain and system capacity in time variant and frequency variant channels. MIMO- OFDM configuration is found to perform better against multi-path fading and the varying channel conditions, than the conventional technologies. Precoding is a new technique that can be applied which helps to improve the performance of a MIMO OFDM system. In this paper, the BER performance of a MIMO-OFDM system using precoding is simulated for BPSK, QPSK, 16 PSK and 16 QAM modulation formats. A precoding matrix is computed at the receiver, and then fed back to the transmitter and BER performance was simulated. It was seen that the system performance improved significantly by using the precoding techniques.

***Keywords*— Precoding; Closed; Open-Loop MIMO-OFDM system; CSI - Channel State Information**

I. INTRODUCTION

OFDM is a multicarrier transmission technique in which data is transmitted on a set of orthogonal independent sub carriers. The wastage of bandwidth due to guard bands is eliminated in OFDM systems along with improvement in performance in multipath environment. In an OFDM system, the high data rate signal is split into several parallel lower data rate streams and transmitted over several narrow band subcarriers. The advantage of using OFDM is that it transforms a frequency selective fading channel into multiple narrow flat fading parallel sub channels. An OFDM system increases the symbol duration in the parallel sub channels and use of cyclic prefix helps to reduce the effect of ISI caused earlier by delay spread. MIMO uses multiple antennas at the transmitter and receiver [1] and its advantages include enhanced capacity with the same transmit power, reduced bit error rate etc. Both rate gains and diversity gains can be achieved using a MIMO system by either transmitting multiple data using different antennas or by transmitting the same data through different antennas so that the effects of fading can be minimised [2]. MIMO OFDM is an air interface system which is used in fourth generation mobile cellular wireless systems. It is mainly used for high data rate transmissions and in frequency selective channels. By using a

MIMO – OFDM system, the advantages of both MIMO and OFDM systems can be achieved together.

In a MIMO system for wireless communication, a number of transmitting and receiving antennas are spatially arranged in such a way that the maximum system capacity is achieved. The bandwidth is efficiently utilized resulting in an increased channel capacity in a MIMO system. But the disadvantage is the increase in complexity of the system as the number of antennas increases. The wireless channel is a time varying channel which behaves differently for different frequencies. The advantages of MIMO systems are exploited by using space time coding and spatial multiplexing techniques. The spectral efficiency can be improved by using spatial multiplexing techniques [3][4]. The capacity of MIMO – OFDM system can be significantly improved by taking into account the channel state information at the transmitter side. This technique is known as precoding technique, where the transmitted signal vector through the antennas is weighted by a factor depending on the channel conditions. This matrix is known as the precoding or the channel matrix. Once this is obtained, the number of independent channels with less correlation between them can be obtained by applying singular value decomposition to the channel matrix and finding the number of significant singular values. For the channel matrix '***H***', singular value decomposition is defined as :

$$\boldsymbol{H} = \boldsymbol{U}\,\Sigma\,\boldsymbol{V}^{\boldsymbol{H}} \tag{1}$$

'***H***' is the channel matrix, 'U' is the left singular vectors matrix, '∑' is the matrix of Eigen values and 'V' is the right singular vectors matrix. The parallel decomposition of MIMO channels is obtained by applying precoding at the transmitter side. Let '$\boldsymbol{x}$' be the input bit stream to be transmitted [5]. The transmitted data stream to the channel '$\widetilde{\boldsymbol{x}}$' is obtained by multiplying the right singular vectors matrix '$\boldsymbol{V}$' as:

$$\boldsymbol{x} = \boldsymbol{V}.\widetilde{\boldsymbol{x}} \tag{2}$$

Assuming the noise as independent and identically distributed Gaussian variable '**n**', the output of the channel is obtained as:

$$\boldsymbol{y} = \boldsymbol{H}\boldsymbol{x} + \boldsymbol{n} \tag{3}$$

At the receiver side, the final output is obtained as:

$$\begin{aligned}\boldsymbol{y} &= \boldsymbol{U}^{\boldsymbol{H}}(\boldsymbol{H}\boldsymbol{x} + \boldsymbol{n}) \\ &= \boldsymbol{U}^{\boldsymbol{H}}(\boldsymbol{U}\boldsymbol{\Sigma}\boldsymbol{V}^{\boldsymbol{H}}\boldsymbol{x} + \boldsymbol{n}) \\ &= \boldsymbol{\Sigma}\,\widetilde{\boldsymbol{x}} + \widetilde{\boldsymbol{n}}\end{aligned} \tag{4}$$

Condition Number is a measure of channel correlation. ie, the degree to which transmissions on the same channel appear to the receiver to be the same. The spatial multiplexing techniques degrade when the condition number of the channel becomes less or as the channel correlation increases. The condition number indicates the number of independent channels which will appear at the receiver side from the transmitter. The more the condition number, more the number of independent channels and hence an improvement in the rate gain. The degradation in the condition number can be overcome by using linear precoding techniques, which is obtained by multiplying the transmitted data vectors by the above precoding matrix. Different precoder designs have been studied and their performance have been analysed in [6][7]. But in precoding techniques, the information about the channel matrix should be known at the transmitter side. However, obtaining this information based on feedback channel is difficult due to its limited bandwidth. The precoding technique hence used is based on a limited feedback with codebook. In this technique, the codebook should be known to both the transmitter and the receiver. The precoding matrix is first quantized and an optimum precoder from the codebook which consists of a set of precoding matrices is chosen and feedback is given. The technique based on this is detailed in [6].

The technique of precoding data is also applied for 4G, WiMAX 802.16 systems, with which low bit error rate can be achieved. The necessity of knowing the channel state information in precoding is achieved by conveying the information from the receiver side to the transmitter side. This channel state information will be used to encode the data. If the channel state information conveyed is perfect, the system capacity will be improved significantly by precoding techniques. But since the feedback channel also requires a bandwidth, this reduces the channel capacity. Hence one of the drawbacks of this technique is that in certain cases the reduction in the channel capacity is observed. Also the channel state information conveyed may not be proper always, because of the delay in feed backing the information from the receiver side to the transmitter side. Because of all this reasons, designing a proper feedback channel and codebook is essential for improving the performance of precoding systems [8].

For a 2 x 2 MIMO system, four paths can exist between the transmit and receive antennas. This may include a direct line of sight (LOS) component and or the other component due to the multipath caused due to the reflection, scattering and diffraction from the environment. If the signal to interference noise ratio is very low for the received bit stream, it is difficult to demodulate the transmitted bit streams in the MIMO system. By including precoding in the transmission of the bit streams, the signal reception in the receive antennas can be improved. Different precoding schemes for spatial multiplexing or transmit diversity techniques have been proposed in [7] [8]. In this paper, we analyse the precoding techniques in spatial multiplexing MIMO systems. The concepts of transmit beamforming is done here in which multiple beams are transmitted simultaneously. The complex weighting matrices for 4 x 4 antenna configurations are specified in [9]. In a 2 x 2 configuration, the precoding signals are generated by the multiplication of the weighting matrix '***F***' with the input signals.

The structure of the paper is as follows. Section I gives an introduction about precoding and its advantages and challenges. Section II discusses the principle of precoding techniques in MIMO – OFDM system. In section III, simulation results are shown for the BER performance obtained for a 2 x 2 MIMO-OFDM system with precoding and without precoding is given. And finally the paper is concluded in section IV.

II. PRECODING PRINCIPLE IN A MIMO – OFDM SYSTEM

The precoding techniques are applied in either frequency division duplex (FDD) or time division duplex (TDD) systems. TDD systems use the same frequency for transmission and reception. Hence the feedback channel can be designed based on this characteristic. In FDD systems the transmitted and received channels are treated as different due to the difference in frequencies. The channel state information feedback matrix will be conveyed to the transmitter based on Fig. 1 shown below.

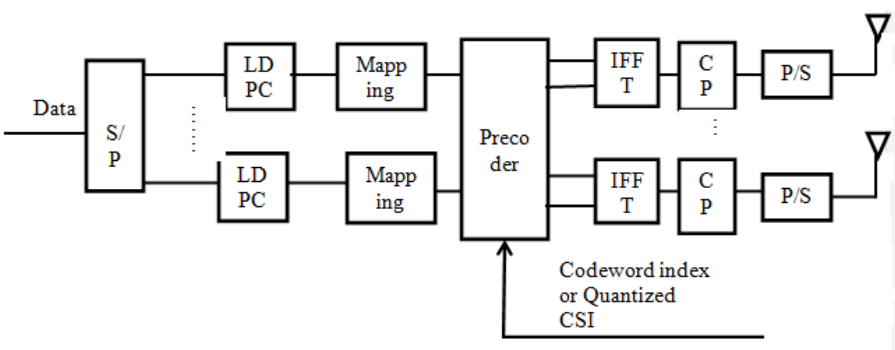

Fig. 1 MIMO – OFDM Transmitter with Precoder

In the above figure, the codeword index or the quantized CSI represents the channel state information which is fed back from the receiver side. The input bit stream is first converted to parallel bit streams using a serial to parallel converter. The output of which is fed to a low density parity check coder followed by a mapping to one of the signal constellations like BPSK, QPSK, 16 PSK, 16 QAM etc. To this modulated signal, precoding is applied by multiplying the input signal stream using a precoding matrix [1] [2] [3]. The precoded signal is then converted back to time domain using IFFT techniques, followed by a cyclic prefix and then transmitted through 'N_t' transmit antennas. The input to the precoder is also the channel state information based on which the precoding matrix is designed.

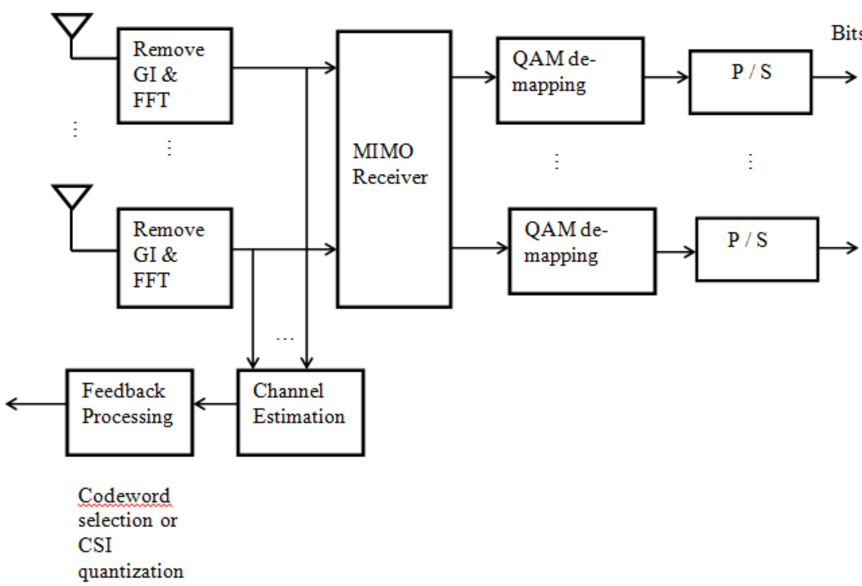

Fig. 2 MIMO – OFDM Receiver with Channel Estimation

In the receiver side, for the received signal, the guard intervals are first removed followed by the conversion into the frequency domain. The output of the MIMO receiver is then de-mapped to derive the bits transmitted. Once the guard bands are removed it is also used to estimate the channel information [3]. The estimated channel information is then fed back to the transmitter side using a feedback processing block.

As shown in Fig. 1 for a MIMO – OFDM system, the output of the serial to parallel converter consists of '*N*' bit streams which is given to the 'N_t' transmitting antennas after doing the processing mentioned above whereas the receiver consists of 'N_r' receive antennas.

The information bits are mapped according to the modulation scheme used [2]. If '$\mathbf{t_k}$' represents the transmitted vector of the 'k^{th}' bit stream as:

$$t_k = [t_{k,1}\ t_{k,2}\ \dots\ t_{k,N_T}] \tag{5}$$

Then the precoded data symbol '$\mathbf{x_k}$' is obtained by multiplying this mapped vector by a precoding matrix '**F**' of dimension 'N_t X N_r' where 'N_t' represents the number of transmitted antennas and 'N' is the length of the data stream.

$$x_k = \sqrt{\frac{E_s}{M}}.F.s_k \tag{6}$$

where 'E_s' is the total transmitted energy for the subcarrier '$\mathbf{s_k}$' of the data stream. Equation 2 represents the transmitted data stream after precoding. At the receiver side, the received signal vector 'r_k' is represented as:

$$r_k = H.x_k + n_k = \sqrt{\frac{E_s}{M}}.H.F.s_k + n_k \tag{7}$$

where 'H' is the channel matrix ('N_r X N_t') and 'n_k' is the Gaussian noise vector of zero mean and unity variance.

III. SIMULATION RESULTS

The performance of a 2 x 2 MIMO OFDM system was simulated with precoding and without precoding applied to the system. The code was simulated on the platform MATLAB R2011a for 1024 bits with 64 subcarriers and tested with the data stream modulated using BPSK, QPSK, 16 PSK and 16 QAM. The parameters of the same are as follows:

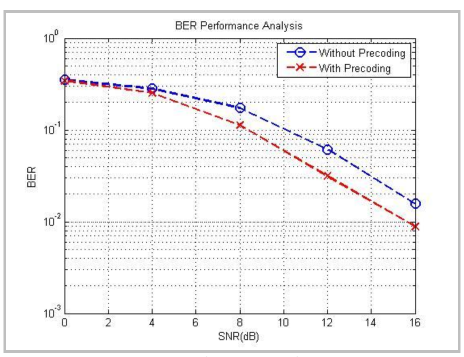

Fig.3 BER Performance of BPSK with & without precoding

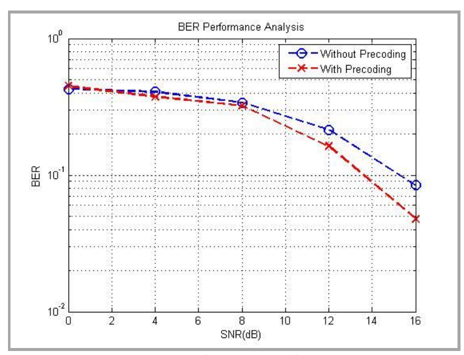

Fig.4 BER Performance of QPSK with & without precoding

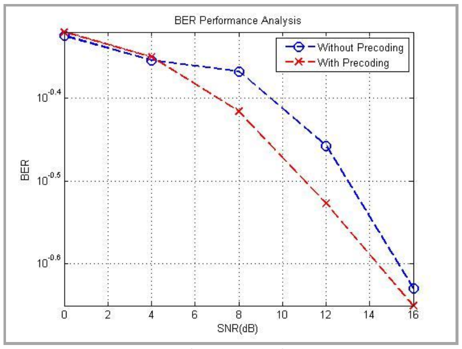

Fig.5 BER Performance of 16 PSK with & without precoding

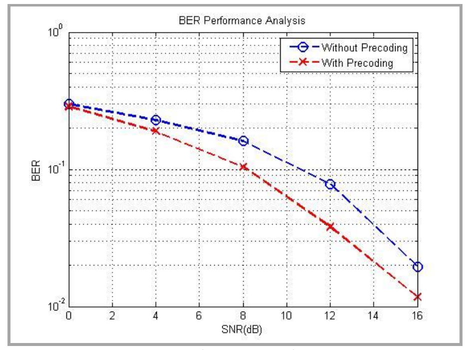

Fig.6 BER Performance of 16 QAM with & without precoding

From the simulation results it is seen that the bit error rate performance improves with precoding techniques. The bit error rate is also seen to be decreasing with an increase in SNR.

IV. CONCLUSION

In this paper, the performance of a precoded closed loop MIMO – OFDM systems is analysed by comparing it with that without precoding. The code was simulated for BPSK, QPSK, 16 PSK and 16 QAM for a 2 x 2 MIMO OFDM system. It was seen that the bit error rate performance obtained is better than that without precoding. In the modulation schemes used the BER performance of BPSK was found to be better than QPSK, 16 PSK and 16 QAM for the same SNR. Although the performance was found to be increasing, still there is a scope for further improvement in BER performance with lower SNR. This needs to be tested with more number of antennas and for varying channel conditions.

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