# A Codebook Selection based Precoding in LTE Systems

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***Abstract***—An efficient transmission system which offers high data rate, capacity and spectral efficiency is one of the key challenges faced by the communication field today. 4G technologies like Long Term Evolution (LTE) systems with MIMO, can be used to achieve high speed in data terminals. Also the precoding methods can be used to mitigate the interferences occurring in the system. In this paper, a codebook selection based precoding method with the channel state information (CSI) is considered to eliminate the interferences. Based on the index information feedback the appropriate precoding matrix can be chosen from the codebook predefined.

***Keywords—****Codebook, Codeword, CSI, LTE, MIMO, PMI, Precoding.*

## I. INTRODUCTION

With evolution of 4G technologies like LTE and emergence of extremely high rate applications such as high-definition video conference, demands to achieve high data rate become inevitable. Multiple Input Multiple Output (MIMO) systems can be used to achieve high data rate and capacity within a given bandwidth. The spectrum available for the communication systems are limited. Hence there is always a need for high data rate transmission with this available bandwidth [1]. The MIMO techniques which uses the multiple antennas at both the transmitter and the receiver section is considered as one of the major research area nowadays. When the data is transmitted from the source it may undergoes certain interferences and the actual signal cannot be obtained at the output [2]. To overcome this issue MIMO OFDM systems are introduced to eliminate the interference occurring in the system through the multipath fading effect.

Long Term Evolution (LTE) standards can be used in wireless communication systems to achieve high speed in data terminals [3]. The 3GPP (3rd Generation Partnership Project) developed the LTE standard and it is specified in its Release 8 document series. The LTE has to be operated on a separate radio spectrum as it is incompatible with the 2G and 3G systems [4]. MIMO based LTE systems can provide high data rate, high capacity and more spectral efficiency. For eliminating the interferences occurring in the MIMO systems several precoding techniques can be used [5]. Precoding is based on transmit beamforming concepts with the provision of allowing multiple beams to be simultaneously transmitted in the MIMO system. These techniques can be used to support the multilayer transmission. All the incoming data are jointly processed well at the transmitter to obtain the actual data at the output. . All the transmitted data are been weighted by a factor depending upon the channel conditions here. Each of the antenna port will contain atleast some bits of data from all the different layers. 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.

Several precoding techniques like Channel Inversion precoding, Block Diagonalization, Dirty Paper Coding, THP etc. are used commonly [6]. In this paper, a codebook based precoding method which use the feedback from the receiver section is considered as an efficient precoding for the LTE systems. Depending on the channel state information obtained from the receiver a proper codeword is selected from the codebook and using that selected codeword input data is precoded. To feedback the channel information, channel estimation is also done at the receiver side [7].

## II. PRECODING IN LTE

Precoding can be used to eliminate the interference occurring in a wireless communication channel. The basic block diagram for a precoding in MIMO based LTE system is shown below.

The input data is scrambled before transmitting it to the modulator. Here in transport layer the bits encoded are been scrambled by the bit wise scrambling sequence. After scrambling the data is given to the modulator block. In modulation section QAM, QPSK, PSK like modulation techniques can be used to convert the scrambled data to complex modulated data symbols. For a two port antenna case, the modulated symbols from both the codewords are mapped to different layers. The data streams which is formed by the process of spatial multiplexing where the data is split into several data streams are the layers. Generally the number of transmit antennas are equal to the number of layers [5].

The layered data from different antenna ports are then transmitted to the precoder section. In precoding, all the incoming data from all the layers get combined in a specific way and then those combined data are distributed to each of the antenna port. Thus each antenna possess at least some of data from all the layers. Here data are combined properly by

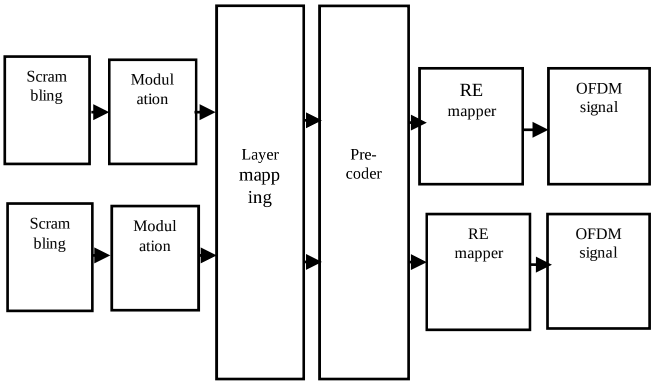


Fig 1. Block diagram showing precoding in LTE

using a precoding matrix. Using predefined codebook the appropriate precoding matrix can be selected.

After precoding the data is then transmitted to the resource element mapper. Here the precoded data from each of the antenna are the mapped to resource elements in the resource block. The number of resource block available can be a function of the channel bandwidth. In OFDMA, users are allocated with a defined number of subcarriers for a particular transmission in the resource blocks. One resource block is formed by a number of resource elements and a group of resource block constitute a resource grid [7]. Thus each element in the resource grid represents a single subcarrier for one symbol period and it is the resource element. In MIMO each of the transmit antenna have separate resource grid.

Consider a 20 MHz bandwidth channel with 100 resource blocks. Let each resource block consists of 12 subcarriers with 15 KHz subcarrier spacing between them. Therefore total 180 KHz spectrum is occupied [3]. Hence among the 20 MHz channel bandwidth, for 100 resource blocks only 18 MHz spectrum is occupied by the data symbols.

The data is then forwarded to the OFDM block for generating the OFDM signal. The serial data coming has to be converted into a parallel format first. This is because as the bandwidth of the signal is greater than the coherence bandwidth, the frequency selective fading may occur. To avoid this situation the signal bandwidth are divided in parallel manner [2]. 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. 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. Data is the transmitted serially through the channels [5]. At the receiver section the cyclic prefix is removed and Fourier transform is performed to obtain the frequency domain signals. The demodulation is performed and the output data is obtained at the receiver end.

## III. CODEBOOK SELECTION BASED PRECODING

Precoding can be used to support the multilayer transmission on a multi antenna wireless communication system.

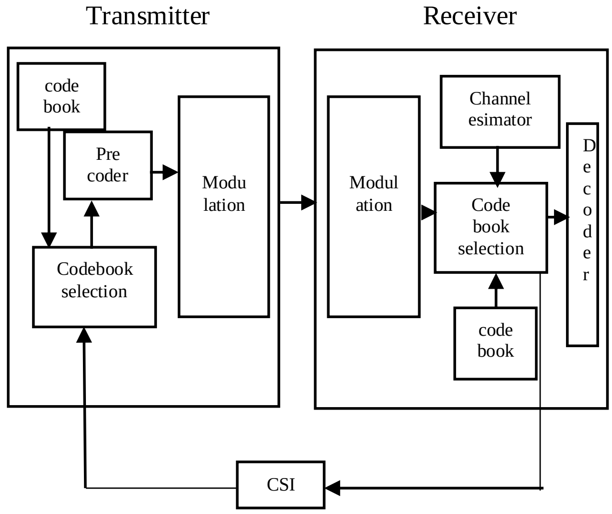


Fig 2. Codebook based precoding

The input signal is given to the transmitter section. Precoding is done insource by selecting an appropriate precoding matrix from the codebook. For that a channel state information has to be feedback from the receiver side [1]. The receiver can inform the UE about the codebook index by setting the precoding information field in the DCI format. Thus after estimating the channel conditions the receiver will send a precoding matrix indicator to the transmitter. This index helps the transmitter to choose the proper precoding matrix from the codebook. Precoding information feedback generally contains 3 bits and meaning of each bit combinations is predefined [7].

On receiving the codebook index from the receiver, the precoding matrix corresponding the same index value is selected from the codebook generated and the input data is precoded. Precoding input is then given to the modulation section where the OFDM signal can be generated. The OFDM signal is then transmitted using the different antenna elements and in the receiver side the signal is demodulated and the desired output can be obtained by eliminating the interferences [6].

### *A. Channel State Information (CSI)*

The known channel properties of a communication link are the channel state information. This shows how the signal propagates from the source to the destination and represents the combined effect of fading, scattering and power decay along with the distance [2]. CSI are generally estimated at the receiver and is feedback to the transmitter. Two types of CSI defined are Instantaneous CSI and Statistical CSI are there.

Instantaneous CSI or short term CSI gives the current channel conditions using the impulse response and the statistical CSI gives the statistical characteristics like fading distribution, LOS component etc. of a channel.

CSI consists of RI. PMI and CQI [2].

1) *Rank Indicator (RI)*

The Rank Indicator shows the number of layers that can be supported under the current channel conditions and modulation schemes. Only a single rank value is reported. The bit width of other fields depends on the reported RI.

2) *Precoding Matrix Indicator (PMI)*

The PMI is calculated based on the reported CSI. It is used to select the appropriate precoding matrix from the codebook generated.

3) *Channel Quality Indicator (CQI)*

CQI is calculated conditioned on the reported RI and PMI. It shows the summary of the channel conditions under the current transmission mode corresponding to the SNR. It can be used to know the modulation and coding schemes for the channel.

## IV. PRECODING IN LTE

The LTE specification defines certain set of predefined weighing matrices for doing the precoding at the transmitter. Consider a 2 x 2 MIMO system which offers four separate connections between the transmitter and receiver. For transmission of signals, there will be a LOS path and several multipath. The signals travelling through the multipath can suffer a lot of interferences and hence the signal cannot be detected properly at the receiver end. By using a precoding at the transmitter section this problem can be eliminated. Precoding schemes can be used for spatial multiplexing and transmit diversity applications [7]. In this paper, precoding matrix for the spatially multiplexed MIMO is considered.

In precoding all the layers are combined before transmission with the aim of equalizing the signal across the multiple receiver antennas. For a 2 x 2 MIMO case the precoded input is given as follows [1],

$$\begin{bmatrix} r^{(0)}(i) \\ r^{(1)}(i) \end{bmatrix} = w(i) \begin{bmatrix} s^{(0)}(i) \\ s^{(1)}(i) \end{bmatrix} \tag{1}$$

where $s^{(q)}$ (i) represents the input data for precoding (q = 0,1) and $r^{(q)}$ (i) are the precoded signal applied to each of the antenna port. w is the weighing matrix or the precoding matrix used to get the precoded output.

Precoding matrix maps each layer to the corresponding antenna dedicated to the transmitting layer without any coupling with other antennas. For a codebook index 0, the weighing matrix is [1],

$$w(i) = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{2}$$

The input data is multiplied with this precoding matrix and the resulting transmit data is given as [1],

$$\begin{aligned} r^{(0)}(i) &= \frac{1}{\sqrt{2}} s^{(0)}(i) \\ r^{(1)}(i) &= \frac{1}{\sqrt{2}} s^{(1)}(i) \end{aligned} \tag{3}$$

For a codebook index 1 provides a linear combination of sums and differences of the two input layers. Hence the precoding matrix is [1],

$$w(i) = \frac{1}{2} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{4}$$

The precoded output is given as [1],

$$\begin{aligned} r^{(0)}(i) &= \frac{1}{2} s^{(0)}(i) + \frac{1}{2} s^{(1)}(i) \\ r^{(1)}(i) &= \frac{1}{2} s^{(0)}(i) - \frac{1}{2} s^{(1)}(i) \end{aligned} \tag{5}$$

If the codebook index to the transmitter is 2 then the weighing matrix is [1],

$$w(i) = \frac{1}{2} \begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix} \tag{6}$$

and the resulting transmit data is given as [1],

$$\begin{aligned} r^{(0)}(i) &= \frac{1}{2} s^{(0)}(i) + \frac{1}{2} s^{(1)}(i) \\ r^{(1)}(i) &= j\frac{1}{2} s^{(0)}(i) - j\frac{1}{2} s^{(1)}(i) \end{aligned} \tag{7}$$

From the Table I. the MIMO with transmission mode 4 can use the 2 codeword with large CDD having codebook index 0. Similarly the transmission mode 0 can use the 2 codeword matrix wiith index 1. All these depends on the Precoding information field in DCI format. The precoding information field content for a 2 antenna port is shown in Table II.

TABLE I. Codebook selection for two antenna ports [1]

| Codebook index | 1 layer | 2 layers |
|---|---|---|
| 0 | $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$ | $\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$ |
| 1 | $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$ | $\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$ |
| 2 | $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$ | $\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$ |
| 3 | $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$ | - |

TABLE II: Content of Precoding information field for 2 antenna ports [1]

| One codeword | | Two codeword | |
|---|---|---|---|
| Bit field mapped to index | Message | Bit field mapped to index | Message |
| 0 | 2 layers: Transmit diversity | 0 | 2 layer with $\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$ |
| 1 | 1 layer with $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$ | 1 | 2 layer with $\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$ |
| 2 | 1 layer with $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$ | 2 | 2 layer: precoding based on latest PMI |
| 3 | 1 layer with $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$ | 3 | reserved |
| 4 | 1 layer with $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$ | 4 | reserved |
| 5 | 1 layer: precoding based on latest PMI | 5 | |
| 6 | 1 layer: precoding based on latest PMI | 6 | reserved |
| 7 | reserved | 7 | reserved |

The generation of the precoded data can be illustrated by considering the constellation diagrams given below. Consider a 2x2 MIMO system with two transmitting layers. Depending on the codeword index fedback from the receiver, the precoding is performed. Fig. 3 shows the simulation result for the precoded data, when precoding matrix indicator 0 is transmitted. For a two layer transmission system, the input data is precoded with the corresponding precoding matrix defined and the precoded data is obtained.

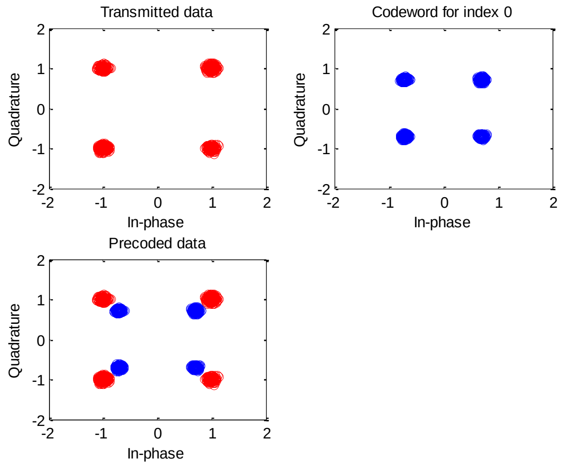


Fig. 3. Precoding data for PMI 0

In Fig. 4, the precoding for the precoding matrix indicator 1 is given. The input data is digitally modulated by using the BPSK modulation scheme and it is then precoded with the corresponding precoding matrix for the codeword index 1.

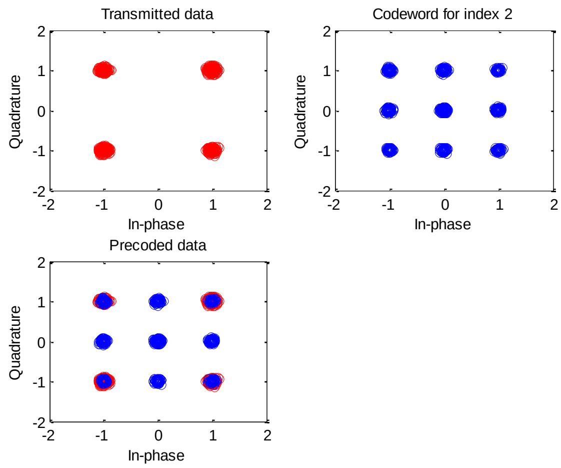


Fig. 4. Precoding data for PMI 1

The data precoding for a MIMO system, when the PMI 2 is fed back is given in Fig. 5. Here also the input data is multiplied with the precoding matrix for PMI 2 and the precoded data is formed. At the receiver section, appropriate decoders can be used to compensate the effect of the precoding in transmitter side. The LTE specification for precoding have four codebook matrix for two transmit antenna and 16 codebook matrices for four antenna case. The CSI should be known for the proper selection of the precoding matrix. If the channel conditions are varying fastly, then delays in the feedback should be reduced.

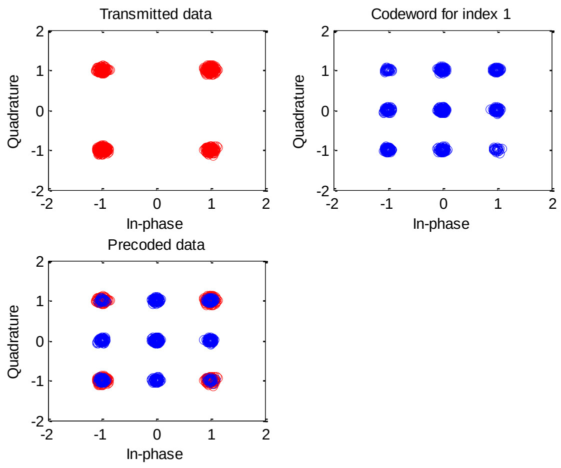


Fig. 5. Precoding data for PMI 2

This reduction in feedback delay and the signaling overhead restrict the codebook selection process. Thus all the effectiveness of precoding get affected. Hence the design of LTE system should be done with the proper understanding of performance, precoding options and feedback constraints.

## V. CONCLUSION

The LTE systems can be used to achieve high speed and data rate in a communication channel. Precoding can be used to eliminate the interferences occurring in the system due to the multipath transmission. In this paper, a codebook selection based precoding method for two antenna port which uses the channel state information for precoding the input data to mitigate the inter user interferences happening in the system was considered. Precoding matrices can be chosen from the predefined codebook based on the PMI available to the transmitter section. Further capacity and performance of the system can be achieved by considering the 4 antenna port MIMO systems also. The four antenna port systems can include four layers with 16 codeword selection.

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