Comparison of Bit Error Rate and Signal to Noise Ratio for Multi-User MIMO Wireless Applications

Battu Deepa, P.Sudhakara Reddy

Abstract—In this paper, we analyze performance of multi-user(MU)multiple-input multiple-output (MIMO) systems which has emerged recently as an important research topic. In the multi-user MIMO system, downlink and uplink channels are referred to as broadcast channel (BC) and multiple access channel (MAC), respectively. In Broadcast channel data transmission application, the coordinated signal detection on receiver side is mixed with interference. It is very essential to avoid this interference by using different transmission methods at transmitter end. Due to high capacity, increased diversity, and interference suppression; the multi-user MIMO systems are effectively used for broadcast channels applications for efficient data transmission in terms of bit rate at transmitter end and getting maximum signal to noise ratio at the receiver end for next-generation wireless applications. In this paper we compare bit-error rate (BER) and signal to noise ratio (SNR), obtain simulation results and made comparison among different transmission methods which are Channel Inversion (CI), Block Diagnolization(BD), DirtyPaper Coding (DPC) and Tomlinson-Harashima Pre-coding (THP) algorithms.

Index Terms—: BER, Broad-cast channel, Multi-user MIMO, Performance comparison, SNR etc.

I. INTRODUCTION

NOWADAYS, the ever-increasing population of wireless communication technology consumers demands faster and more convenient communications in radio frequency (RF) bands. In Wireless communications, the capacity of the channel, channel band width, signal power parameters are initially identified design parameters. In addition to this, Multi-inputandMulti-output(MIMO) technique is adapted recently forbetter wireless communications and other design parameters such as dimension, space are included. This can be exploited to increase the data throughput of a wireless system, without requiring an increase in transmission power or expansion of bandwidth [1].The researches on MIMO systems are extended to the multiuser cases which can be classified as MIMO multiple access channel (MAC) and MIMO broadcast channels (BC) [2].Here we focused on performance comparison ofmulti-user MIMO BC system. The challenge is to employ a method that is able to take the parameters taken into account such as BER and SNR, and is also identified to apply to most of wireless applications[3].

Section 2, describes the Mathematical analysis of Multi-user MIMO up/down link data reception/transmission is discussed. In section 3,Various Multi-user transmission techniques are discussed. The simulation results of four data transmission techniques are shown and compared results are mentioned in section 4. Finally, Conclusions and future directions are noted in section 5.

II. MATHEMATICAL ANALYSIS OF MULTI-USER MIMO SYSTEM

Let us consider K independent users in the multi-user MIMO system. We assume that the Base station (BS) and each Mobile station(MS) are equipped with N_B and N_M antennas, respectively. Figure 1 shows the uplink channel, known as a multiple access channel (MAC) for K independent users [4]. Let $x_u \in \mathbb{C}^{N_M \times 1}$ and $y_{MAC} \in \mathbb{C}^{N_B \times 1}$ denote the transmit signal from the u th user, u = 1, 2….K, and the received signal at the BS, respectively.

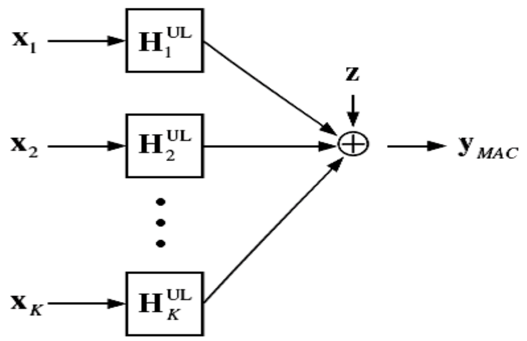

Fig.1.Uplink channel model for Multi-user MIMO System: multiple access channel (MAC).

The channel gain between the u[th] user MS and BS is represented by $H_u^{UL} \in \mathbb{C}^{N_B \times N_M}$,u=1,2,…..K,and the received signal expressed as

$$y_{MAC} = H_1^{UL} X_1 + H_2^{UL} X_2 + \cdots + H_K^{UL} X_K + z (1)$$

$$= \left[H_1^{UL} H_2^{UL} \ \dots \ H_K^{UL}\right] \begin{bmatrix} X_1 \\ \vdots \\ X_k \end{bmatrix} + Z (2)$$

$$= H^{UL} \begin{bmatrix} X_1 \\ \vdots \\ X_k \end{bmatrix} + Z (3)$$

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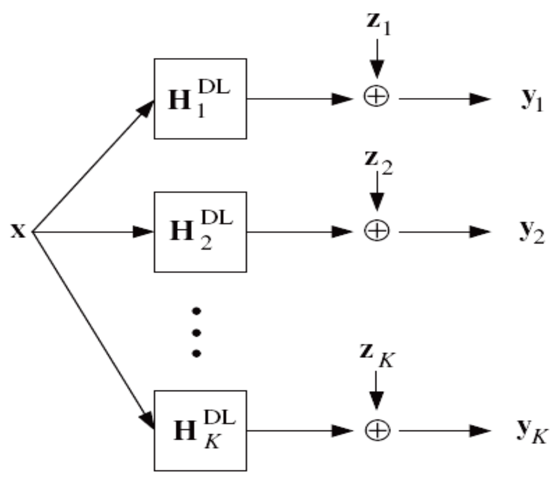

Fig. 2. Downlink channel model for multi-user MIMO System: Broadcast channel (BC).

On the other hand Figure 2shows the downlink channel, known as a broadcast channel (BC) in which $x \in C^{N_B \times 1}$is the transmit signal from BS and $y_u \in C^{N_M \times 1}$ is the received signal at the uth user , u=1,2,3….K. let $H_u^{DL} \in C^{N_M \times N_B}$ represent the channel gain between BS and the u th user .

In BC the received signal expressed as

$$y_u = H_u^{DL} x + Z_u \text{u} = 1,2, \ldots \text{k}(4)$$

Where $Z \in C^{N_M \times 1}$is the additive noise at the uthuser.

The effect of self-interference due to the increase of spatial correlation in a MIMO channel has become one of the limiting factors towards the implementation of future network downlink transmissions. To reduce the effect of interference in a downlink MU-MIMO transmission different transmission methods had been proposed [5]-[10].

III. MULTI-USER MIMO DATA TRANSMISSION

A. Multi-user Transmission via Linear Processing

The first class of multi-user transmission approaches we consider is based on linearprocessing; linearpre-coding techniques are generally two types, 1).Block diagnolization2). Channel inversion[11]-[13].

1) Block Diagnolization: Block Diagnolization (BD) is a linear pre-coding technique for the downlink of MU MIMO systems. It decomposes a MU MIMO downlink channel into multiple parallel orthogonal single-user MIMO channels [14]-[16]. The signal of each user is pre-processed at the transmitter using a modulation matrix that lies in the null space of all other users' channel matrices. Thereby, the MUI in the system is efficiently set to zero. BD is attractive if the users are equipped with more than one antenna.

Let $N_{m,u}$denote the number of antennas for the uth user, u =1, 2… K. For the uth user signal $x_{\tilde{u}} \in C^{N_{m,u} \times 1}$, the received signal $\boldsymbol{y_u} \in C^{N_{m,u} \times 1}$ is given as

$$y_u = H_u^{DL} \sum_{k=1}^{K} W_k \;\; x_{\tilde{k}} + Z_u(5)$$

$$= H_u^{DL} W_u \;\; x_{\tilde{u}} + \sum_{k=1, k \neq u}^{K} H_u^{DL} W_k \;\; x_{\tilde{k}} + Z_u$$

Where$H_u^{DL} \in C^{N_{m,u} \times N_B}$ is the channel matrix between BS and the u th user, $W_u \in C^{N_B \times N_{m,u}}$is the Pre-coding matrix for the u th user, and Z_u is the noise vector. Consider the received signals for the three-user case (i.e., K =3),

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} H_1^{DL} & H_1^{DL} & H_1^{DL} \\ H_2^{DL} & H_2^{DL} & H_2^{DL} \\ H_3^{DL} & H_3^{DL} & H_3^{DL} \end{bmatrix} + \begin{bmatrix} W_1 \; x_{\tilde{1}} \\ W_2 \; x_{\tilde{2}} \\ W_3 \; x_{\tilde{3}} \end{bmatrix} + \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} (6)$$

Where $H_u^{DL} W_k$form an effective channel matrix for the uth user receiver and the kthuser transmit signal the interference-free transmission will be warranted as long as the effective channel matrix in equation (6) can be block-diagonalized, that is,

$$H_u^{DL} W_k = 0_{N_{m,u} \times N_{m,u}}, \forall u \neq k(7)$$

In order to meet the total transmit power constraint, the pre-coder $W_u \in C^{N_B \times N_{m,u}}$ must be unitary, u= 1, 2…K. Under the condition of equation (7), the received signal in equation (5) is now interference-free, that is,

$$y_u = H_u^{DL} W_u \;\; x_{\tilde{u}} + Z_u(8)$$

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2) Channel Inversion: A simple way of dealing with inter-user interference is by imposing the constraint that all interference terms be zero. We assume N_M=1 for all users and K =N_B. Let $x_{\tilde{u}}$ denote the uth user signal while $H_{DL} \in C^{1 \times K}$ denotes the channel matrix between BS and the u^{th} user, u = 1,2, . . . K. The received signal of the u^{th} user can be expressed as denotes the channel matrix between BS and the u^{th} user, u=1; 2; .. . ; K. The received signal of the u^{th} user can be expressed as

$$y_u = H_u^{DL} \begin{bmatrix} x_{\tilde{1}} \\ \vdots \\ x_{\tilde{k}} \end{bmatrix} + Z_u; \; \text{u} = 1,2, \ldots \ldots \text{K}(9)$$

The received signal at each user terminal in the above equation is a scalar while each user's received signal in equation $y_u = H_u^{DL} + Z_u$ is a vector. Since each user is equipped with a single antenna, interferences due to other signals cannot be canceled. Instead, pre-coding techniques such as channel inversion and regularized channel inversion can be considered.Ultimately, the drawbacks of channel inversion are due to the stringent requirement that the interference at the receivers be identically zero.

B. Multi-user Transmission via Non-Linear Processing

The Multi-user transmission via non-linear processing is classified in to two types. These are 1).Dirty Paper coding 2).Tomlinson-Harashima Precoding.

1) Dirty Paper Coding: We now turn to a nonlinear technique based on the concept of "writing on dirty paper" introduced by Costa [17]-[18]. In theory DPC would be implemented when channel gains are completely known on the transmitter side. DPC is a method of pre-coding the data such that the effect of the interference can be cancelled subject to some interference that is known to the transmitter.

Let us consider the case of N_B =3, K =3, $N_{M,u} = 1$, u =1,2,3. If the u[th] user signal is given by $\tilde{x_u} \in \mathrm{C}$, then the received signal is given as

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} \mathrm{H}_1^{\mathrm{DL}} \\ \mathrm{H}_2^{\mathrm{DL}} \\ \mathrm{H}_3^{\mathrm{DL}} \end{bmatrix} \begin{bmatrix} \tilde{x_1} \\ \tilde{x_2} \\ \tilde{x_3} \end{bmatrix} + \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} (10)$$

Where $\mathrm{H}_{\mathrm{u}}^{\mathrm{DL}} \in \mathrm{C}^{1\times 3}$ is the channel gain between BS and the u[th]user. The channel matrix H^{DL} can be LQ decomposed as

$$\mathrm{H}_{\mathrm{u}}^{\mathrm{DL}} = \begin{bmatrix} \mathrm{l}_{11} & 0 & 0 \\ \mathrm{l}_{21} & \mathrm{l}_{22} & 0 \\ \mathrm{l}_{31} & \mathrm{l}_{32} & \mathrm{l}_{33} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} (11)$$

The received signalis

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} \mathrm{l}_{11} & 0 & 0 \\ \mathrm{l}_{21} & \mathrm{l}_{22} & 0 \\ \mathrm{l}_{31} & \mathrm{l}_{32} & \mathrm{l}_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} (12)$$

The received signal of the first user is given as

$$y_1 = \mathrm{l}_{11} x_1 + Z_1 (13)$$

From the first-user perspective, therefore, the following condition needs to be met for the interference-free data transmission:

$$x_1 = \widetilde{x_1} (14)$$

From equation (14), it can be seen that the pre-coded signal $\boldsymbol{x_1}$ is solely composed of the first user signal $\tilde{\boldsymbol{x_1}}$. From equations (12) and (14), the received signal of the second user is given as

$$y_2 = \mathrm{l}_{21} x_1 + \mathrm{l}_{22} x_2 + Z_2 = \mathrm{l}_{21} \widetilde{x_1} + \mathrm{l}_{22} x_2 + Z_2 (15)$$

From equation (15), it can be seen that the following pre-coding cancels the interference component, $\mathrm{l}_{21}\mathrm{x}_1$or $\mathrm{l}_{21}\widetilde{x_1}$, on the transmitter side:

$$x_2 = \widetilde{x_2} - \frac{\mathrm{l}_{21}}{\mathrm{l}_{22}} \quad x_1 = \widetilde{x_2} - \frac{\mathrm{l}_{21}}{\mathrm{l}_{22}} \widetilde{x_1} (16)$$

Same procedure repeated for the received signal of the second user.

2) TOMLINSON- HARASHIMA Pre-coding: Tomlinson-Harashima pre-coding (THP) is a non-linear pre-coding technique developed for single-input, single-out-put (SISO) multipath channels. In fact combination of DPC with modulo operation turns out to be THP [19].Based on the assumption of perfect CSI at the transmitter, several different approaches for designing TH pre-coder for broadcast channels have been proposed, including Zero-forcing (ZF) designs, Minimum mean square error (MMSE) and designs with independent mean square error constraints.

Let us take an example of TH pre-coding for K=3. Let $\{x_u^{TH}\}_{u=1}$ denote the TH pre-coded signal for the u[th] user referring to equations (14), (16) and using modulo operation, THpre-coded data symbols are represented as

$$x_1^{TH} = mod_A(\widetilde{x_1}) = \widetilde{x_1} (17)$$
$$x_2^{TH} = mod_A(\widetilde{x_2} - \frac{\mathrm{l}_{21}}{\mathrm{l}_{22}} x_1^{TH}) (18)$$
$$x_3^{TH} = mod_A(\widetilde{x_3} - \frac{\mathrm{l}_{31}}{\mathrm{l}_{33}} x_1^{TH} - \frac{\mathrm{l}_{32}}{\mathrm{l}_{33}} x_2^{TH}) (19)$$

Where $mod_A(x) = x + 2A.m + j2A.$ m, nis integer values

IV. SIMULATION RESULTS

The main difficulty for transmission over MIMO channels is the separation or equalization of the parallel data streams, i.e the recovery of the components of the transmitted vector 'x' which interfere at the receiver side. The linear equalization is used for separation of data at receiver side with facing a problem of noise improvement and poor efficiency. This dis-advantage is overcome by using a non-linear decision-feed-back equalizer (DFE) at receiver end. It introduces an error in propagation of signals in channels. From the analysis the DFE and THP has the same performance results.The table 1 shows the comparison of the Linear and Non Linear pre-coding techniques for both ISI and MIMO channels at Transmitter/Receiver.

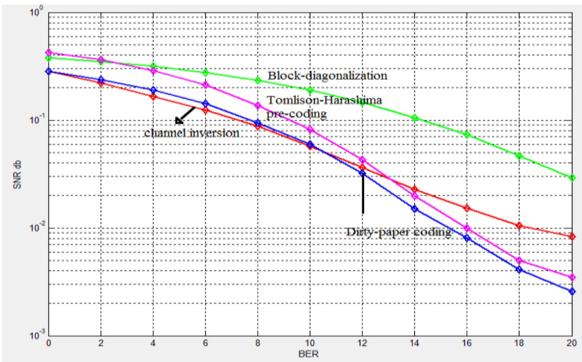

Fig. 3. Multi-user MIMO broaadcasst techniques

In this work, we analyze bit error rate (BER) and signal-to noise ratio (SNR) at receiver.The performance comparison of four algorithms such as channel inversion, block Diagonalization, dirty-paper coding and Tomlinson-Harashima pre-coding techniques are done using matlab tool. BER performance of N_T=4, number of users are 20, where four users are selected out of twenty users, BER performance of Block-diagnolizationfor $N_T = 4$,number of users are two where the average bit error rate is taken for both users while employing a zero-forcing detection at the receivers, and BER performance of dirty-paper coding or Tomlinson-Harashima pre-coding for $N_T = 4$,number of users are 10,where fourusers are selected out of ten users. In this comparison transmitted power of DPC is higher than that of THP. Note that the reduced transmit power of THP is attributed to modulo operation in the pre-coding process.

Figure 3 shows the comparison of the multi-user broadcast transmission methods, in terms of SNR and BER. From this simulation results it is observed that the better performance is obtained in terms of BER, the non-linear pre-coding techniques are better compared to linear pre-coding techniques in multi-user MIMO system.

Table 1.Equalization strategies for ISI and MIMO Channels.

		ISI Channel	MIMO Channel
Linear	At Rx	Linear Equalizationviainverse of Temporal Equalization	Linear Equalizationvia inverse of Spatial Equalization
	At Tx	Linear Pre-equalization via inverse of Temporal Equalization	Linear Pre-equalizationvia inverse of Spatial Pre-equalization

	At Rx/Tx	OFDM/DMT, Vector pre-coding	SVD
Non-Linear	At Rx	DFE	Matrix DFE
	At Tx/Rx	THP	MIMO-THP

V. CONCLUSION AND FUTURE DIRECTIONS

A MIMO system plays an important role in fourth generation wireless systems to provide advanced data rate. In order to attain the advantages of MIMO systems, it is necessary that the receiver and/or transmitter have access CSI.In Broadcast channel data transmission application, the coordinated signal detection on receiver side is mixed with interference. It is very essential to avoid this interference by using different transmission methods at receiver end. The multi-user MIMO systems are effectively used for broadcast channels applications for efficient data transmission in terms of bit rate at transmitter end and getting maximum signal to noise ratio at the receiver end for next-generation wireless applications. In this paper we analyzed bit-error rate (BER) at transmission side and signal to noise ratio (SNR) at the receiver side, and obtain simulation results and made comparison among different transmission methods such as Channel Inversion (CI), Block Diagnolization(BD),Dirty paper coding(DPC) and Tomlinson-Harashima Pre-coding(THP) algorithms.

In MIMO Channels, the information for the desired throughput can be achieved by using the DPC method, which employs at transmitter end.From the simulation results, it is observed that the non-linear pre-coding techniques are better than the linear pre-coding techniques. Among non-linear pre-coding techniques Dirty-paper coding given better performance compare to THP algorithm in case of perfect CSI. For better performance for multi-user MIMO system we need efficient coding techniques in order to get accurate results at receiver side and also required new ISI cancellation methods.The design of THP in an imperfect CSI is the best future direction for a MIMO-BC system. The Optimization in design and analysis of THP for MU-MIMO systems has wide research for next generation wireless applications.

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