An efficient technique for Interference Cancellation in Broadcast Channel of Multiuser MIMO system

Dalveer Kaur and Neeraj Kumar

Abstract— In Multiuser MIMO system, multiple antennas are placed on base station and also on multiple users. Multiple antennas technique enhanced the performance parameters like reliability and data rate of wireless communication system without required more bandwidth, multiple antennas at transmitting and receiving end provides transmitting and receiving diversity, diversity increases the reliability of signal and spatial multiplexing increases the data rate by transmitting multiple information streams between transmitter and receiver. The base station transmits multiple streams to mobile station through downlink channel, known as broadcast channel and mobile users also transmit multiple streams to base station through uplink channel, known as multiple access channel. This paper considers only broadcast channel, the major issue in information transmission in broadcast channel is that the desired signal on the receiving side is affected by other user interference as well as inter-antenna interference. So, interference cancellation schemes on the transmitting end plays very important role to reduced interference on receiving end in multiuser MIMO wireless communication system. This paper discusses two interference cancellation schemes, Block Diagonalization (BD) and Dirty Paper Coding (DPC). Block Diaganalization is linear precoding technique that is used at transmitting end and it uses singular value decomposition operation to get block diagonalization precoding weights. Dirty Paper Coding is non-linear precoding technique; this technique is applied only when channel gains are completely known at transmitting end. This paper also shows performance comparison of block diagonalization and dirty paper coding schemes in term of Bit Error Rate.

Keywords: Multiuser MIMO, Block Diagonalization, DPC

I INTRODUCTION

MIMO technique was first introduced for point to point or Single User communication system, in this technique; multiple antennas are placed on base station and mobile station. SU-MIMO plays very important role in Long Term Evolution (LTE), which needs 300 Mb/s data rate for Downlink Channel (DLC) and 75 Mb/s for Uplink Channel (ULC).

The authors are with the IKG Punjab Technical University Main Campus, Kapurthala, Punjab, India. dn_dogra@rediffmail.com

In LTE advanced, the data rate target is approximately 1 Gb/s for DLC and 500 Mb/s for ULC. MU-MIMO is the key technique to achieve the date rate 1 Gb/s in DLC. In MU-MIMO system, more than one user is used and all users are equipped with multi antennas and base station with multiple antennas provides services to multiples users simultaneously. Fig.1 shows the Single User and Multiuser communication system [1-4].

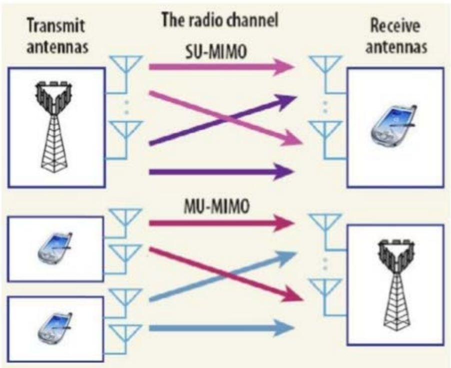

Fig.1. SU-MIMO and MU-MIMO system

I.A CHALLENGES IN MU-MIMO

There are two challenges in a multiuser MIMO scenario, one is uplink challenge and second one is downlink challenge. The uplink problem is addressable by using array processing and multi-user detection can be done by base station for separating signals sent by user. The downlink problem is to be analyzed differently. There is much similarity between Multi User-MIMO downlink and single user MIMO, however the receiver antennas are distributed among different independent users. This may cause a problem while decoding the received symbols since joint decoding requires that every user has all symbols received from receiver antennas of all the users. This level of coordination it too hard to achieve [5].

Majority of the techniques use processing of the symbols at the transmitting end itself to address the downlink issue, the process being called precoding. Precoding, however also had been employed in Single User MIMO systems as an option and for the further improvement of the SNR at the receiver. In MU-MIMO however, precoding is very much essential to mitigate inter user interference [6]. Here, the channel state information of downlink is used for precoding. The downlink channel information of each user must be known to the transmitter for modeling the transformation variables of every user. Many precoding techniques have been proposed in order to address the problems in transmitting and receiving the symbols in multi user MIMO system. This paper covers two precoding techniques, namely Block Diagonalization and Dirty Paper Coding.

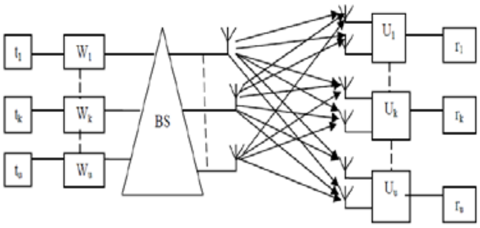

Fig. 2 Multi User-MIMO Downlink scenario with precoding

I.b BLOCK DIANALIZATION PRECODING

In Single User MIMO system, Channel Inversion precoding techniques are used to cancel or mitigate interference. In the channel inversion precoding, all signals other than the target signal is considered as interference, and canceled from received symbol by using precoding [2]. A method involving multiple antenna system for multiple users can be applied, which is similar in sense to single user system. From target user point of view, the problem of enhancement in the noise becomes severe when the interference between the antennas and other user interference gets canceled or mitigated in the process of channel inversion. The Block Diagonalization method can be more suitable in this case. This method causes the reduction in the interference due to other user signals by precoding, which is not same in case of channel inversion. Various signal detection techniques can then be employed to mitigate inter antenna interference for every user [7].

Fig.2 shows that MU-MIMO downlink scenario with precoding at transmitting end, Let us consider $N_{A.k}$ are the number of antennas for k^{th} user, k=1,2,3……u and t_u is transmitted symbol by the base station and received symbols r_k at k^{th} user can be expressed as

$$r_k = C_k^{DL} \sum_{u=1}^{u} w_u \ t_u + n_k \tag{1}$$

Where; C^{DL} is channel matrix between base station and k^{th} user, w_u is the precoding weight matrix for u^{th} user and n_k is the noise vector. Consider three number of users (u=3) in MU-MIMO scenario, so equation (1) can be expressed in matrix form

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} C_1^{DL} & C_1^{DL} & C_1^{DL} \\ C_2^{DL} & C_2^{DL} & C_2^{DL} \\ C_3^{DL} & C_3^{DL} & C_3^{DL} \end{bmatrix} \begin{bmatrix} w_1 t_1 \\ w_2 t_2 \\ w_3 t_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} C_1^{DL} w_1 & C_1^{DL} w_2 & C_1^{DL} w_3 \\ C_2^{DL} w_1 & C_2^{DL} w_2 & C_2^{DL} w_3 \\ C_3^{DL} w_1 & C_3^{DL} w_2 & C_3^{DL} w_3 \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \tag{3}$$

Equation (3) shows that $C_k^{DL} w_u$ is the effective channel matrix for the k^{th} user and the u^{th} user transmit symbol. The received signal for user 1 can be expressed as

$$r_1 = C_1^{DL} w_1 t_1 + C_1^{DL} w_2 t_2 + C_1^{DL} w_3 t_3 + n_1 \tag{4}$$

Equation (4) shows that $C_1^{DL} w_1 t_1$ is the desired value for user 1 and remaining contents in equation (iv) are interference plus noise to user 1. If these contents $C_1^{DL} w_2 t_2$ and $C_1^{DL} w_3 t_3$ are zero. So receiver can received desired value without any interference. The inference free transmission will be possible if effective channel matrix is Block Diagonalized, that is

$$C_k^{DL} w_u = 0 \ \text{ for } k \neq u \tag{5}$$

Equation (5) shows that the effective channel matrix coefficient is the combination of channel coefficient and precoding weight. So, the precoding matrix w_u must be design to lie in null space of C_k^{DL}. If equation (5) is satisfies for three number of users (u=3). The received signal without any interference can be expressed as

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} C_1^{DL} w_1 & 0 & 0 \\ 0 & C_2^{DL} w_2 & 0 \\ 0 & 0 & C_3^{DL} w_3 \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \tag{6}$$

I.c DIRTY PAPER PRECODING

This precoding technique is employed at transmitter side. This technique is applicable only when the transmitter knows the channel gains completely before transmission. Dirty paper coding precedes the data in such a way; the effect of interference can be cancelled subject to some interference that is known at transmitting end [5].

II MATHEMATICAL MODEL OF DIRTY PAPER CODING

Consider number of antennas at base N_B =3, number of users u=3 (K=1, 2, 3) and number of antennas at mobile user $N_{A.K}$ =1. If k^{th} user signal is t_k', the received can expressed as

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} C_1^{DL} \\ C_2^{DL} \\ C_3^{DL} \end{bmatrix} \begin{bmatrix} t_1{'} \\ t_2{'} \\ t_3{'} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \quad (7)$$

Where C_k^{DL} is the channel gain between base and k^{th} user. The channel matrix can be decomposed in terms of L and Q.

$$C_k^{DL} = \begin{bmatrix} L_{11} & 0 & 0 \\ L_{21} & L_{22} & 0 \\ L_{31} & L_{32} & L_{33} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix} \quad (8)$$

Where Q_i (i=1, 2, 3) are orthonormal row vectors. Let Consider t_k (k=1, 2, 3) are precoded signal for t_k'(k=1,2,3) . The effect of Q is eliminated in equation (8) by transmitting Q^H t. The equation (7) can be write as

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} C_1^{DL} \\ C_2^{DL} \\ C_3^{DL} \end{bmatrix} Q^H t + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}$$

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} L_{11} & 0 & 0 \\ L_{21} & L_{22} & 0 \\ L_{31} & L_{32} & L_{33} \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \quad (9)$$

The received signal at user number one can be expressed from equation (9)

$$r_1 = L_{11} t_1 + n_1 \quad (10)$$

Equation (10) shows that the interference free data transmission is possible when precoded signal is

$$t_1 = t_1{'} \quad (11)$$

The received signal at user number two can be expressed from equation (11)

$$r_2 = L_{21}\, t_1 + L_{22}\, t_2 + n_2 = L_{21}\, t_1{'} + L_{22}\, t_2 + n_2 \quad (12)$$

Now, precoded signal t_2 can be expressed from equation (xi)

$$t_2 = t_2{'} - (L_{21} / L_{22})\, t_1{'} \quad (13)$$

The received signal at user number three can be expressed from equation (9)

$$r_2 = L_{31}\, t_1 + L_{32}\, t_2 + L_{33}\, t_2 + n_3 \quad (14)$$

The precoded signal t_3 can be expressed from equation (xii)

$$t_3 = t_3{'} - (L_{31} / L_{33})\, t_1 - (L_{32} / L_{33})\, t_1 \quad (15)$$

The precoded signals are in equation (1), (2) and (3) can be expressed in matrix form as

$$\begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} t_1{'} \\ t_2{'} \\ t_3{'} \end{bmatrix} \quad (16)$$

$$\begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ -(L_{21} / L_{22}) & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} t_1{'} \\ t_2{'} \\ t_3{'} \end{bmatrix} \quad (17)$$

and

$$\begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -(L_{31} / L_{33}) & -(L_{32} / L_{33}) & 1 \end{bmatrix} \begin{bmatrix} t_1{'} \\ t_2{'} \\ t_3{'} \end{bmatrix} \quad (18)$$

Dirty Paper Coding precoded signals can be expressed in matrix form by combining above three matrix equations (14), (15) and (16).

$$\begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -(L_{31} / L_{33}) & -(L_{32} / L_{33}) & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 \\ -(L_{21} / L_{22}) & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} t_1{'} \\ t_2{'} \\ t_3{'} \end{bmatrix} \quad (19)$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ -(L_{21} / L_{22}) & 1 & 0 \\ -(L_{31} / L_{33}) + (L_{32}\, L_{21} / L_{33} L_{22}) & -(L_{32} / L_{33}) & 1 \end{bmatrix} * \begin{bmatrix} t_1{'} \\ t_2{'} \\ t_3{'} \end{bmatrix} \quad (20)$$

The precoded signals values are put in equation (9) and received signals at every user can be represent in matrix form

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} L_{11} & 0 & 0 \\ L_{21} & L_{22} & 0 \\ L_{31} & L_{32} & L_{33} \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 \\ -(L_{21} / L_{22}) & 1 & 0 \\ -(L_{31} / L_{33}) + (L_{32}\, L_{21} / L_{33} L_{22}) & -(L_{32} / L_{33}) & 1 \end{bmatrix} \begin{bmatrix} t_1{'} \\ t_2{'} \\ t_3{'} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \quad (21)$$

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} L_{11} & 0 & 0 \\ 0 & L_{22} & 0 \\ 0 & 0 & L_{33} \end{bmatrix} \begin{bmatrix} t_1{'} \\ t_2{'} \\ t_3{'} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \quad (22)$$

Equation (22) shows that each user received signal without any interference.

III. SIMULATION RESULTS

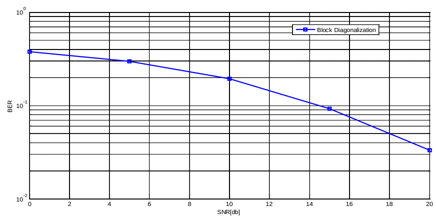

Fig.3 BER Performance of Block Diagonalization precoding with zero forcing detection at receiving end (No of antennas at base station N_B = 4, Number of users U= 4 and Number of antennas at each user $N_{A,1}$= $N_{A,2}$ =2)

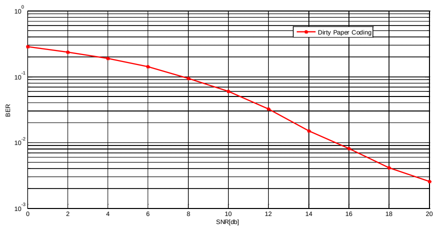

Fig.4 BER Performance of Dirty Paper Coding at transmitting end (No of antennas at base station $N_B = 4$, Number of users U= 4 and Number of antennas at each user $N_{A,1}= N_{A,2} =2$)

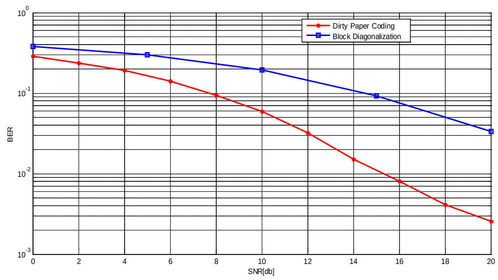

Fig.5 BER Performance comparison of DPC and Block Diagonalization

IV CONCLUSION

This paper shows the mathematical model of Block Diagonalization and Dirty Paper Coding precoding techniques for multiuser MIMO system. The BER performance of these two techniques are measured and shown in Fig. 3 and Fig.4 respectively. Their BER performance comparison is also shown in Fig.5. It is concluded thereby that performance of Dirty Paper Coding is much better than the Block Diagonalization in terms of BER.

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