Block diagonalization for Multi-user MIMO Beamforming performance over Rician Channel

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Abstract - *In traditional wireless cellular networks, wireless mobile communication faces adversities due to noise and fading. At same cell, users can cause the co-channel interference (CCI) between each other. Thereby, CCI can deteriorate the downlink channel's capacity. Depending on the multiple-input multiple-output (MIMO) system theory, wireless communication network systems researches have been important developments. MIMO system is used to overcome individual channel fading effect by employing spatial multiplexing. Exploiting the matrix of channel state information (CSI) can improve performance of wireless channel link. CCI which is created via additional users inside the cell borders can be limited by designing the beamforming precoding vectors for every user in Multi-User MIMO system (MU-MIMO). Linear precoder has number of methods; one of them is Block diagonalization (BD) method. This method using by beamforming precoding as a linear precoder in the MU-MIMO broadcast channel system that transmits various information streams without interference to manifold users. This paper presents evaluation of the BD precoding performances in MU-MIMO beamforming over a Raylegh fading channel with CSI. Then, the channel matrix replaces the typical channel assumption with its correlated realistic Rician fading channel. Simulation results show that the Rician fading channel has performance improvement until with low Rician factor value, compared to a conventional channel. The high value of Rician factor can reduce the error rate.*

Key Words: Block diagonalization; Beamforming; CSI; Fading; MU-MIMO

1.INTRODUCTION

In all wireless communication systems, the broadcast environment when the system transmits information over wireless channel will be described as Line of Sight (LOS) or Non Line of Sight (NLOS). In case of NLOS, the data that is transmitted over a wireless channel has Rayleigh distribution as the probability density function (PDF). On the other hand, in case of LOS, the data that is transmitted over wireless channel has Rician distribution as PDF [1].

In general, transmitting data through a wireless channel may lead to the possibility of changes to the data, causing errors. The error probability for a fading channel is inversely proportional to the signal-to-noise ratio (SNR). Each wireless channel has an individual and independent fading channel that is different from the other channels [2]. Based on space–time theory, the performance of any wireless system is improved through a powerful tool generated by using suitable techniques (at the receiver node) and signaling (at the transmitter node), together with a number of antennas at both sides of the wireless communication network nodes [3].

Increasing numbers of wireless communication customers lead to reuse frequency for the efficient use of the available spectrum. Unfortunately, the reason for decreasing system capacity and service quality may be because of interference that comes from increased frequency reuse. Therefore, the MIMO system has captured significant attention, considering its possible ability to improve the capacity of wireless channel networks. For this reason, MIMO systems have been extensively studied due to their features. Nevertheless, it has been depending on the unreality models of channels such as Rayleigh and the Rician fading channel, which is presumption and theoretical channel to evaluate the performance of MIMO systems [4].

In MU-MIMO scenarios, numerous mobile stations in the same cell in same time or frequency slots share the same base station and try to contact it. In this case, many co-channels occur. According to the participation fact of reuse the sources in MU-MIMO systems, the system suffers from multi-user interference. Linear precoding in the base station which is installed at a fixed location and decoding at the user approaches are necessary to solve this problem [5]. To mitigate the co-channel interference which occur by mobile stations must encouraged the designer to design a transmitter can send the information to several mobile stations by beamforming vectors. Particularly, there has been significant attention given to MU-MIMO systems as a future technology for LTE-Advanced, which promises to provide optimal execution to wireless communication systems [6]. It should be mentioned that at any time a sender of a MIMO system has no information about the CSI, neither multi-user diversity nor spatial multiplexing can be achieved [7]. On the other hand, if the CSI of all mobile stations is available at the transmitter, then the precoder is capable of fully removing CCI. By removing CCI, each user can communicate with the transmitter over an interference-free, single-user channel [8]. Therefore, through an imperfect feedback channel, reconnaissance of limited CSI and employment of CSI is very critical point for a MIMO system [9]. In cases when the channel state information at the transmitter (CSIT) is on hand and using a MIMO system with a liner precoding technique, it can accrue additional profits [10]. CSIT is very important, because when it is fully available at the base station, the MIMO system performs best in numerous ways via using the precoding method. For example, to mitigate symbol interference, precoding can be used with spatial diversity and spatial multiplexing provided by the MIMO system. Besides high gain coding, if space–time codes can be combined with precoding, maximum gain diversity is available [10] [11]. The BD method that supports multiple-stream transmission for MU-MIMO system can be considered as one of the biggest promising approaches [12]. In [13], in the MU-MIMO scenario where every user has a number of antennas try to connect with base station in wireless communication network, BD precoding have been presented as a precoding of linear method [14]. Therefore, it have been proposed BD algorithm to get beamforming technique with uncomplicated way, this technique which do not depend on time or frequency slots sent to each mobile station linear group of data in the same time or frequency slots. Nevertheless, BD and zero forcing (ZF) approaches put limitation on design of the system which is the antennas number for the transmitter and receiver. In this paper, we have analyzed and presented an evaluation of the BD at the transmitter for the wireless fading channel as transmission media to the signal and ZF detection at the receiver when CSI exists. We also discuss our simulation of the performance of an MU-MIMO beamforming system that employs BD with ZF and transmits the signal over a Rayleigh fading channel (in the NLOS environment) and then over a correlated realistic Rician fading channel (in the LOS environment).

2. MU-MIMO BROADCAST SIGNAL MODEL

We have considered an environment of downlink MU-MIMO broadcast channel consisting of U geographically sparse mobile stations communicates with the base station (BS) has M antennas. In such this environment system, each user is independent and employing $\mathrm{N_u}$ antennas of user u. These users will receive their own signal, as shown in Fig. 1. Define $N_T = \sum_{u=1}^{U} N_u$ as the total users' antennas number.

For a typical wireless communication network, we imagine that $N_T \leq M$ with the independent channels of flat fading. Suppose that the intended message signal for the user u is the scalar s_u. Therefore, the transmitted symbol vector to U users is:

$$S = [s_1, s_2, \cdots, s_U]^T, \tag{1}$$

In the precoding step, we denote to the matrix of precoding as:

$$\mathbf{W} = [w_1, w_2, \cdots, w_U], \tag{2}$$

where $w_u \in C^{M \times 1}$ is the joint precoding vector (beamforming coefficients) for uth user. After joint precoding step, the symbol is multiplied by beamforming vector and then the transmitted vector would be:

$$X = \sum_{u=1}^{U} w_u s_u = \mathbf{WS}, \tag{3}$$

The symbol $\mathrm{s_u}$ and the coefficients of beamforming precoding w_u will be normalized as follows:

$$\mathrm{E}|s_u|^2 = 1, \ ||w_u||^2 = 1$$

It is assumed that signals $\mathbf{WS} \in C^{M \times 1}$ are broadcast over the channels denoted as:

$$\mathbf{H} = [H_1{}^T, H_2{}^T, \cdots, H_U{}^T]^T, \tag{4}$$

where $H_u \in C^{N_u \times M}$ describes the channel coefficients between $\mathrm{N_u}$ receiver antenna at uth user and BS antennas as:

$$H_u = \begin{bmatrix} h_u^{(1,1)} & \cdots & h_u^{(1,M)} \\ \vdots & \ddots & \vdots \\ h_u^{(N_u,1)} & \cdots & h_u^{(N_u,M)} \end{bmatrix} \tag{5}$$

where $h_u^{(n,m)}$ denotes the channel coefficient between the base station which has mth transmitter array antenna and uth user which has the nth receiver array antenna.

Thus, the received signals at receivers' antennas as:

$$\mathbf{y} = [\mathbf{y}_1{}^T, \mathbf{y}_2{}^T, \cdots, \mathbf{y}_U{}^T]^T = \mathbf{H}\,\mathbf{WS} + \mathbf{n}, \tag{6}$$

where $\mathbf{y}_i \in C^{N_i \times 1}$ representing the signal which is received at ith recipient, whilst for the additive noise is denoted by $\mathbf{n} \in C^{UN_i \times 1}$. When we have given careful consideration to each user separately, we will find the received signal at an ith recipient as:

$$\mathbf{y}_i = H_i \sum_{u=1}^{U} w_u s_u + n_i = H_i w_i s_i + H_i \sum_{u=1, u \neq i}^{U} w_u s_u + n_i, \tag{7}$$

The H_i vector has complex Gaussian variables components with unit-variance and zero-mean.
Moreover, the components of the additive noise n_i have distribution as $N(0,\sigma_i^2)$ and is temporarily white and spatially.

3. FADING CHANNAL MODEL

Usually, the strongest propagation component of MIMO channel corresponds to specular component (due to LOS propagation also referred to as deterministic components). While all the other components are scattering components (due to NLOS also referred to as random components) [**2**]. When there is no component of LOS (for K= 0), in this case, the channel fading is described by the Gaussian distribution with a variance of σ^2 and zero mean or Rayleigh distribution as:

$$\sigma = \sqrt{\frac{1}{K+1}}$$

where K is Rician factor value. The channel fading distribution has been following the Gaussian distribution with a variance of σ^2 and mean of q or Rician distribution when K increases (For K > 0) as:

$$q = \sqrt{\frac{K}{K+1}}, \qquad \sigma = \sqrt{\frac{1}{K+1}}$$

Therefore, in this work, channel matrix of MIMO system is tends to be described as [15]:

$$\mathrm{H} = \sqrt{\frac{K}{K+1}}\, H_d + \sqrt{\frac{1}{K+1}}\, H_r \qquad (8)$$

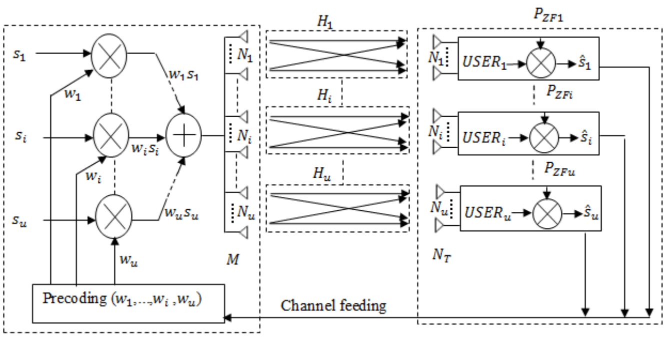

Fig -1: Block diagram of the multiple independent SU-MIMO beamforming system.

Where H_d representing the component of the normalized deterministic channel matrix, while H_r representing the component of random channel matrix, $\|H_d\|^2 = N_T\, M$, E{ $|[H_r]_{i,j}|^2$ }= 1, i = 1: N_T, j = 1: M [15]. While K is known as factor of the Rician channel which is the relation between the component of the specular power c^2 and the component of scattering power $2\sigma^2$, displayed as [2]:

$$\mathrm{K} = \frac{\|\mathrm{H_d}\|^2}{\mathrm{E}\{|[\mathrm{H_r}]_{i,j}|^2\}} = \frac{c^2}{2\sigma^2}, \qquad (9)$$

3. DOWNLINK PRECODING

In the system introduced in section MU-MIMO broadcast signal model can be used two precoding methods, which is linear and non-linear precoding method. Precoding can be used in MIMO to mitigate or cancel the inter user interference. We concentrate on linear precoding methods in this paper, because it is lower complexity. One of these linear precoding methods is BD. BD method is compatible with the multiple users, every user has multiple antennas. By the precoding process of this method, the interference signal that is coming from other user signals will be canceled. Therefore, MU-MIMO channel model will be converted into multiple independent single user MIMO channels model by BD method [2].

We suppose that the CSI of the wireless communication network in the cell is recognized to BS in Frequency-division duplexing (FDD) or Time-division duplexing (FDD) systems. In FDD systems, BS can get the downlink CSI by feedback of the users at same cell. While in TDD systems, according to channel reciprocity, BS can correctly guess the downlink CSI duo to the uplink CSI.

BD Precoding

Let $\tilde{\mathrm{H}}$ is H with out $\mathrm{H_i}$, then compute the null space of all users except ith user by SVD to $\tilde{\mathrm{H}}$:

$$\begin{bmatrix} \mathrm{H}_1 \\ \vdots \\ \mathrm{H}_{i-1} \\ \mathrm{H}_{i+1} \\ \vdots \\ \mathrm{H}_U \end{bmatrix} = \tilde{\mathrm{U}}_i\, \tilde{\Lambda} \left[\tilde{\mathrm{V}}_i^{b} \quad \tilde{\mathrm{V}}_i^{ns}\right]^{\mathrm{H}} \qquad (10)$$

where $\tilde{V}_i^{ns}$ is the null space of all users except ith user. Then:

$$\begin{bmatrix} H_1 & \tilde{V}_i^{ns} = 0 \\ & \vdots \\ H_{i-1} & \tilde{V}_i^{ns} = 0 \\ H_{i+1} & \tilde{V}_i^{ns} = 0 \\ & \vdots \\ H_U & \tilde{V}_i^{ns} = 0 \end{bmatrix}, \qquad (11)$$

Therefore, the broadcast through the MU-MIMO channel by any user in this system is look like to the user transmitted through a single-user MIMO channel system (SU-MIMO). Thereby, any cell has a BS work with MU-MIMO system is converting into cell has a BS work with multiple independent SU-MIMO system. Now to compute the equivalent SU-MIMO channel of ith user V_i^b , we can use SVD as suitable precoding techniques.

$$H_i \tilde{V}_i^{ns} = U_i \Lambda [V_i^b \quad V_i^{ns}]^H \qquad (12)$$

Where V_i^{ns} is the null space of ith user, while V_i^b is the beam of ith user. Then, the precoding matrix W_i for ith user under the condition $N_T \leq M$ is:

$$w_i = \tilde{V}_i^{ns} V_i^b \qquad (13)$$

By substituting (11) and (13) into (7), we can obtain

$$y_i = H_i \sum_{u=1}^{U} w_u s_u + n_i$$

$$= H_i x_i + 0 + n_i , \qquad (14)$$

we can note that the received signal is consist of the required signal of ith user as $x_i = w_i s_i$ only.

ZF Detection

The ZF approach nullifies the interference of inter-stream by the following weight matrix [2]:

$$P_{ZF} = (H^H H)^{-1} H^H . \qquad (15)$$

where $(.)^H$ denotes Hermitian transposition. Then, the received signal y_i multiplies by P_{ZF} from the left as space filter output:

$$P_{ZF}\, y_i = P_{ZF}\,(H_i x_i + n_i)$$

$$= x_i + (H^H H)^{-1} H^H n_i$$

$$= x_i + n_{ZF}. \qquad (16)$$

From (16), it can note that the performance of error is immediately linked to the n_{ZF} ($|| n_{ZF} ||^2$).

4. SIMULATION RESULTS AND EVALUATION

In this part, It was evaluated the signal-to-noise ratio (SNR) against the bit error rate (BER) as a scale of precoding efficiency. A typical MU-MIMO scheme is imitated to estimate the performance of the suggested MU-MIMO beamforming precoding scheme over Rician fading channel as a realistic channel in comparison to the same scheme over Rayleigh fading channel as conventional channel. For random Rayleigh and Rician fading channel cases, the samples of these parameters are set up to 10000 with elements generated as zero-mean for Rayleigh fading channel while m-mean for Rician fading channel and unit-variance independent and identically distributed (i.i.d) complex Gaussian random variables.

We simulate for {2, 2} × 4, {2, 2, 2} × 6, {3, 3, 3} × 9 and {4, 4, 4} × 12 MU-MIMO system, where the average BER is taken of BD approach at BS while the receiver was using a ZF approach. BS transmits by N_u antennas to each user over the noise and flat fading channel while each user has employed N_u antennas to receive the signal. QPSK signal constellation has been used as a broadcast modulation in all simulations and the results are averaged through several channel investigations. For all receivers the noise variance per receive antenna is supposed the equal, $\sigma_1^2 = \ldots = \sigma_K^2 = \sigma^2$. Notice that BD is used in the BS as precoding method and ZF is used in the user as detection method. While the MU-MIMO beamforming system transmit the data over conventional channel has bad results with regard to BER (Fig. 2.), the realistic channel gives a suitable BER in the existence of 2 and 3 dynamic users. To best comprehend the behavior of the suggested scheme, the BER was plotted for different values of k (k > 0), compared to the Rayleigh fading channel. BD may well remove the multiuser interference perfectly, but it as well minimize the power of wanted receive signal, then has capacity loss particularly at low SNR (16).

Therefore, Fig. 2 illustrates that noise is the major factor restricting the performance of system in the situation of low

SNRs. The two users, for different k, enjoys with a better presentation than three users. On second thought, multiuser interference turns into the major factor restricting the performance of system for high SNRs. Then the three users, for different k, have performs better than two users. For the same reasons, Fig. 3 illustrates that to achieve high performance with high number of antennas it need to high SNR. Therefore, the multiplicity of antennas in mobile devices is impractical. Specifically due to size, hardware or cost practical limitations wireless mobile devices may not be able to support high number of antennas.

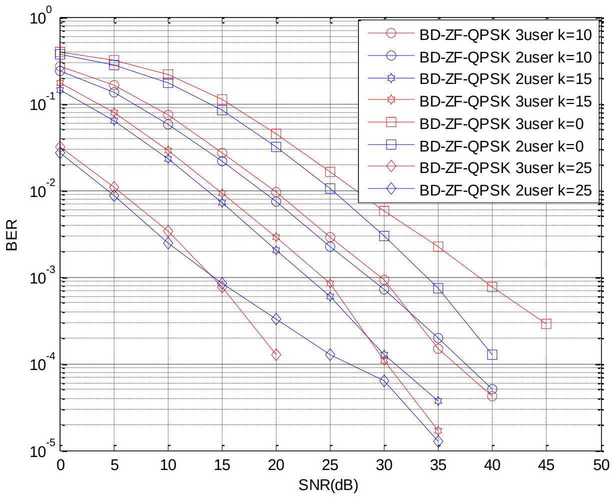

Fig -2: BER performance of MU-MIMO system using BD at the transmitter and ZF detection at 3 receivers each equipped with 2,3and4 receive antennas.

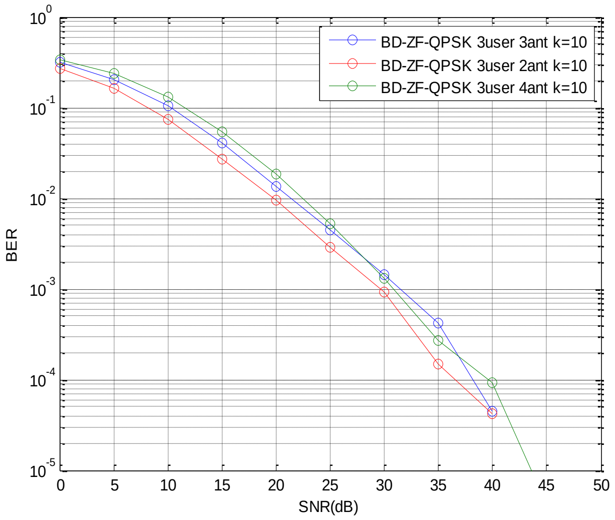

Fig- 3. BER performance of MU-MIMO system using BD at the transmitter and ZF detection at 3 receivers each equipped with 2,3and4 receive antennas.

CONCLUSION

The significant topic of various MIMO downlink fading channel models using pragmatic beamforming by BD precoding and ZF detection is addressed here. This paper presents evaluation of the MU-MIMO downlink channel system's precoding performance after it has been converting into multiple independent SU-MIMO downlink channels system over Rayleigh fading channel and Rician fading channel and its parameters, given estimated CSI. The simulation results discovered how to MU-MIMO system precoding could achieve great performance improvement over realistic channel with high SNR for different Rician factor (k > 0) compared to conventional channel, i.e., Rayleigh fading channel. Rayleigh fading is not realistic because it has stationary performance. Therefore, it is not appropriate enough to estimate the performance of wireless communication channels compared to Rician fading channel spatially with MU-MIMO beamforming system.

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