Combining Alamouti STBC with Block Diagonalization for Downlink MU-MIMO System over Rician Channel for 5G

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***Abstract*— Wireless communication faces a number of adversities and obstacles as a result of fading and co-channel interference (CCI). Diversity with beamformer techniques may be used to mitigate degradation in the system performance. Alamouti space-time-block-code (STBC) is a strong scheme focused on accomplishing spatial diversity at the transmitter, which needs a straightforward linear processing in the receiver. Also, high bit-error-rate (BER) performance can be achieved by using the multiple-input multiple-output (MIMO) system with beamforming technology. This approach is particularly useful for CCI suppression. Exploiting the channel state information (CSI) at the transmitter can improve the STBC through the use of a beamforming precoding. In this paper, we propose the combination between Alamouti STBC and block diagonalization (BD) for downlink multi-user MIMO system. Also, this paper evaluates the system performance improvement of the extended Alamouti scheme, with the implementation of BD precoding over a Rayleigh and Rician channel. Simulation results show that the combined system has performance better than the performance of beamforming system. Also, it shows that the combined system performance of extended Alamouti outperforms the combined system performance without extended Alamouti. Furthermore, numerical results confirm that the Rician channel can significantly improve the combined system performance.**

***Index Terms*— Fading, CCI, STBC, Alamouti, MIMO, Beamforming, BD, CSI.**

I. INTRODUCTION

Today's wireless network's customers need to more quality of service (QoS). Therefore, fifth generation (5G) of wireless networks promises to deliver that and much more. It is highly expected that future 5G networks should achieve a 10-fold increase in connection density, i.e., 10^6connections per square kilometers [1] and increase in the volume of mobile traffic, e.g., beyond a 500-1000-fold increase in mobile traffic [2]. Unfortunately, the current radio access technology, within the limited available time/frequency spectrum, is facing challenges to meet the requirements of technological advances presented by the 5G network. Therefore, new solutions must be identified and developed that can make significant gains in capacity and QoS for network customers to ensure continued sustainability of radio access technologies. To date, 5G is still being studied; and research groups and companies are working together to determine the exact nature of 5G. On the other hand, it is not yet clear which technologies will do the most for 5G in the long run, but a few early favorites have emerged. The front-runners include beamforming technology. At once, it is possible to achieve signal-to-noise-plus-interference-ratio (SINR) improvements through the adoption of beamforming precoding at the transmit side [3]. There is the potential to utilise a block diagonalization (BD) initiative to design transmitting beamforming vectors without any degree of complexity. One such approach is to secure a precoding matrix for all mobile stations. This type of matrix will lie in the null spaces of other mobile stations' channel matrix, and thus, the beamforming approach may be seen to depend on each mobile station's spatial data [4]. Unfortunately, the desired power of the received signal will be decreased. The BD algorithm that supports multiple-stream transmissions for multi-user MIMO (MU-MIMO) systems, in which every user has several antennas trying to connect with the base station, can eliminate the co-channel interference (CCI) completely [5]. When no information concerning the channel state information (CSI) is held by a MIMO system sender, spatial multiplexing and multi-user diversity are not possible [6]. Additional profits can accrue when the CSI at the transmitter is available and using a MIMO system with a liner precoding technique [7]. If all mobile stations' channel state information is available in the transmitter, the precoder would then have the ability to completely remove CCI. By removing CCI, each user can communicate with the transmitter over an interference-free way, as single-user channel [3]. Therefore, through an imperfect feedback channel, reconnaissance of limited CSI and employment of CSI are critical points for a MIMO system [8]. CSI 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-block-code (STBC) can be combined with precoding, maximum gain diversity is available [9]. Owing to the use of wireless fading channels, it is common for error performance to demonstrate further degradation in terms of the wireless network's mobile communication system.

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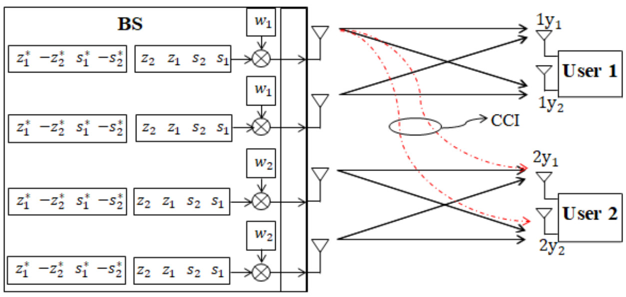

Fig. 1. Block diagram of the proposed MU-MIMO system, *s* is the data of 1st user and z is the data of 2nd user.

It is important to note that, diversity has become recognised as a key communication approach when seeking to enhance the performance of wireless systems without incurring significant expense [10] [11]. Diversity, in essence, may be achieved at the transmitter and/or the receiver side [10]. However, should diversity be received in an instance of downlink, there will be a notably high consumption of power, owing to the fact that the majority of computational burden is assigned to the mobile side. Accordingly, a non-complex decoding processing can be achieved at the mobile side through the base station-located application of STBC [10] [12] [13] [14].

The primary and most well-recognised diversity is identified as the STBC, which has come to be accepted as a powerful and extremely valuable diversity approach in overcoming the effects of wireless channel fading. In this regard, the Alamouti scheme is seen to be a complicated orthogonal STBC; this affords simplistic decoding and encoding processing at the receiver and transmitter side, respectively. This was originally devised and presented by Alamouti [15]. In an effort to decrease error performance degradation levels in mobile units and accordingly attain greater improvements in wireless links, the Alamouti scheme can be combined with beamforming precoding [16] [17] [18] [19]. Beamforming scheme based on BD technology combined with STBC enables the multi-user MIMO (MU-MIMO) system to provide good QoS, thereby absorbing more users, and makes it promising to address the 5G requirement of massive connectivity, specifically in the Internet of things (IoT) and massive machine-type communications (mMTC) scenarios, which are considered as types of 5G application scenarios [20]. In these scenarios, users may be low-cost sensors deployed in a small area, where both the line-of-sight (LoS) and the non-line-of-sight (NLoS) exist, which can be better modeled by the Rician fading channel. In [21] and [22], 5G cellular systems on MU-MIMO transmitters use linear precoding. In this report, the system performance within regards to the Alamouti scheme undergoes both analysis and evaluation, with BD precoding applied when there is the presence of CSI. Furthermore, the performance of an MU-MIMO beamforming system, alongside the utilisation of BD with the extended Alamouti scheme, is discussed, with the signal in the NLoS setting transmitted (Rayleigh fading channel) as well as in the LoS environment (correlated realistic Rician fading channel).

The superscripts$(\cdot)^T$, $(\cdot)^*$ and $(\cdot)^H$ denote transpose, complex conjugate, and Hermitian operations, respectively.

II. ALAMOUTI CODING

The Alamouti code is recognised as being the first and most widely known STBC, and is described as being a complicated orthogonal spice-time-code most applicable in the case of two transmits antennas [15].

Primarily, the Alamouti space-time-coding approach is taken into account, with generalisation in relation to the three transmits antennas then considered [23].

a. Alamouti Space-Time Code

Alamouti designed and presented a complicated orthogonal space-time block code for two transmit antennas [15]. In the case of the Alamouti encoder, there is the encoding of s_1 and s_2 , notably two consecutive symbols complete with the space-time codeword matrix outlined below:

$$S_{A\ 2.antenna} = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \quad (1)$$

As can be seen when reviewing the equation (1), there is the transmission of the Alamouti encoded signal from the two transmit antennas over the two different symbol periods. Throughout the preliminary symbol period, s_1 and s_2 are transmitted at the same time from the two transmit antennas. Throughout the secondary period, there is the repeated transmission of the symbols, with the first transmit antenna transmitting $-s_2^*$ whilst the second transmit antenna transmits s_1^*.

b. Extended Alamouti

As has been discussed in other works [24], the Alamouti scheme has the underpinning foundation of extension, which is seen to derive through extension for 4x1-diversity order. In this case, it is further extended in mind of the 3x3-diversity order [10]. Accordingly, it is necessary to take into account the block diagram representation depicted in the Fig. 2 below, which shows the extended Alamouti code for 3 transmit antennas and 3 receive antennas over the eight different symbol periods for four symbols s_1, s_2, s_3 and s_4.

$$S_{A\ 3.antenna} =$$

$$\begin{bmatrix} s_1 & -s_2 & -s_3 & -s_4 & -s_1^* & s_2^* & s_3^* & s_4^* \\ s_2 & s_1 & s_4 & -s_3 & s_2^* & s_1^* & s_4^* & s_3^* \\ s_3 & -s_4 & s_1 & s_2 & -s_3^* & -s_4^* & s_1^* & s_2^* \end{bmatrix} \quad (2)$$

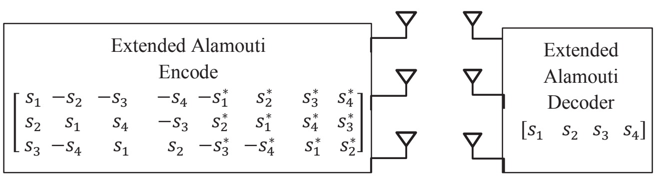

Fig. 2 Extended Alamouti Scheme for 3x3.

III. MU-MIMO BEAMFORMING SYSTEM MODEL

In MU-MIMO system we have considered an environment of U geographically sparse mobile stations as multi-user (MU) communicates with the MIMO base station (BS) which has M antennas. In such a system environment, each mobile station is independent and employing N_u antennas of user u. These users will receive their own signal, as shown in Fig.1 (block diagram of 2 users). The total number of users' antennas is defined as;

$$N_T = \sum_{u}^{U} N_u \tag{3}$$

Also, this system has an operation condition which is $N_T = M$ with the independent channels of flat fading. The meant message signal for the uth user is the scalar S_u. Thereby, the transmitted symbol vector to U users is:

$$S_T = [s_1, \ldots, s_u, \ldots, s_U\ ]^T \tag{4}$$

It should be mentioned that $S_u = S_{A\ 2.antenna}$ for two transmit antennas and $S_u = S_{A\ 3.antenna}$ for three transmit antennas. In the second step, we denote to precoding matrix step as:

$$W = [w_1, \ldots, w_u, \ldots, w_U\ ] \tag{5}$$

where $w_u \in C^{N_u\, xM}$ is the joint beamforming coefficients for uth user. Then the transmitted symbol vector is multiplied by the precoding matrix as third step to produce the precoding data as:

$$X = \sum_{u=1}^{U} w_u s_u = WS \tag{6}$$

The symbol s_u and the coefficients of beamforming precoding w_u will be normalized as follows:

$$E|s_u|^2 = 1, ||w_u||^2 = 1$$
$$for\ u=\{1,\ \ldots,\ U\}.$$

In the broadcast step, we assumed that signals $WS \in C^{N_u\, xM}$ are broadcasted over the channels denoted as:

$$H = [H_1^T\ , \ldots, H_u^T, \ldots, H_U^T]^T \tag{7}$$

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

$$H_u = \begin{bmatrix} h_u^{(1,1)} & \ldots & h_u^{(1,M)} \\ \vdots & \ddots & \vdots \\ h_u^{(N_U,1)} & \ldots & h_u^{(N_U,M)} \end{bmatrix} \tag{8}$$

where $h_u^{(n,m)}$ denotes the channel matrix ingredient, which is located between the mth transmitter array antenna of base station and the nth receiver array antenna of uth user. Thus, at users' antennas the received signals are:

$$y = [y_1^T, \ldots, y_u^T, \ldots, y_U^T]^T = H\ WS + n \tag{9}$$

where $y_u \in C^{N_u\, x\, M}$ is representing the signal which is received at uth recipient, whilst for the additive noise is denoted by n. When we have given careful consideration to each user separately, we will find the received signal at an ith recipient as:

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

$$y_i = H_i w_i s_i + H_i \sum_{u=1, u \neq i}^{U} w_u s_u + n_i$$

$$y_i = H_i x_i + H_i \sum_{u=1, u \neq i}^{U} x_u + n_i \tag{10}$$

where x_i is precoding data of ith user and x_u is precoding data of other users as interference for uth user. The H_i vector has complex Gaussian variable 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 are temporarily white.

IV. DOWNLINK CHANNEL MODEL

Due to LoS propagation the strongest propagation component of MIMO channel corresponds to deterministic component (also referred to as specular components). On the other hand, all the other components are random components (due to NLoS also referred to as scattering components) [10]. The broadcast channel distribution has been following the Rayleigh channel distribution, which is Gaussian distribution with a variance of σ^2 and zero mean. That means there is no component of LoS (K= 0): $\sigma = \sqrt{\frac{1}{K+1}}$. On the other hand, when there is any component of LoS (For $K > 0$) the broadcast channel distribution has been following the Gaussian distribution with a variance of σ^2 and mean of q or Rician distribution when K increases as: $q = \sqrt{\frac{K}{K+1}}$, $\sigma = \sqrt{\frac{1}{K+1}}$.
Therefore, in this work, channel matrix of the MIMO system described as [25]:

$$H = \sqrt{\frac{K}{K+1}}\, H_d + \sqrt{\frac{1}{K+1}}\ \ H_r \tag{11}$$

where H_d representing the component of the normalized deterministic channel matrix, while H_r representing the component of random channel matrix, with $||\ H_d\ ||^2 = N_T\ M$, $E\{\ |[H_r]_{i,j}|^2\}= 1$, $i = 1{:}\ N_T$, $j = 1{:}\ M$ [25]. 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 [10]:

$$K = \frac{\|H_d\|^2}{E\left\{\left|[H_r]_{i,j}\right|^2\right\}} = \frac{c^2}{2\sigma^2} \tag{12}$$

V. BLOCK DIAGONALIZATION PRECODING

Block Diagonalization precoding (BD) method is compatible with the multiple users, every user has multiple antennas. By the precoding process of this method, the interference signal which 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 [10].

Briefly, definition of BD precoding matrix starts from the channel of all users except *i*th user as:

$$\widetilde{H}_i = [H_1 \dots H_{i-1} \ H_{i+1} \dots H_U \ ]^T \tag{13}$$

where $\widetilde{H}_i$ is H with out H_i , then we should compute the null space $\tilde{V}_i^{ns}$ of all users except *i*th user by singular value decomposition (SVD) to $\widetilde{H}_i$:

$$SVD \ of \ \widetilde{H}_i = \ \widetilde{U}_i \ \tilde{\Lambda} \ [\ \tilde{V}_i^b \ \ \tilde{V}_i^{ns} \ ]^H \tag{14}$$

where $(.)^H$ denotes Hermitian transposition. To prevent other users interference multiplies H_i by $\tilde{V}_i^{ns}$, and then uses SVD again:

$$SVD \ of \ H_i \tilde{V}_i^{ns} = \ U_i \ \Lambda \ [\ V_i^b \ \ V_i^{ns} \ ]^H \tag{15}$$

where V_i^{ns} is the null space of *i*th user, while V_i^b is the beam of ith user. Therefore, we can get the precoding matrix w_i for ith user from $\tilde{V}_i^{ns}$ and V_i^b under the condition $N_T \leq M$ as:

$$w_i = [\tilde{V}_i^{ns} \ V_i^b \ ] \tag{16}$$

Now under the condition $\widetilde{H}_i \tilde{V}_i^{ns} = 0$, we substitute (16) into (10), we can obtain:

$$y_i = H_i x_i + 0 + n_i \tag{17}$$

where y_i represents the received signal which is consisted of the required signal of *i*th user and noise without multiuser interference. Note that x_i is Alamouti space-time coding. Therefore, y_i is represented by $1y_{1a}$, $1y_{2a}$, $2y_{1a}$ and $2y_{2a}$:

$$\begin{bmatrix} 1y_{1a} & 2y_{1a} \\ 1y_{2a} & 2y_{2a} \end{bmatrix} = H_i \ w_i \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} + n_i \tag{18}$$

where $1y_{1a}$ and $1y_{2a}$ represents the received signals at the first time in first and second antenna respectively, while $2y_{1a}$ and $2y_{2a}$ represents the received signals at the second time in first and second antenna respectively:

1st time

$$1y_{1a} = \left[h_i^{(1,1)} \dots \ h_i^{(1,M)}\right] w_i \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + n_i \tag{19}$$

$$1y_{2a} = \left[h_i^{(2,1)} \dots \ h_i^{(2,M)}\right] w_i \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + n_i \tag{20}$$

2nd time

$$2y_{1a} = \left[h_i^{(1,1)} \dots \ h_i^{(1,M)}\right] w_i \begin{bmatrix} -s_2^* \\ s_1^* \end{bmatrix} + n_i \tag{21}$$

$$2y_{2a} = \left[h_i^{(2,1)} \dots \ h_i^{(2,M)}\right] w_i \begin{bmatrix} -s_2^* \\ s_1^* \end{bmatrix} + n_i \tag{22}$$

then:

$$1y_{1a} = C\, s_1 + D\, s_2 + n_i, \quad 2y_{1a} = D\, s_1^* - C\, s_2^* + n_i \tag{23}$$

$$1y_{2a} = Q\, s_1 + P\, s_2 + n_i, \quad 2y_{2a} = P\, s_1^* - Q\, s_2^* + n_i \tag{24}$$

where *C, D, Q* and *P* represents the multiplication of channel by precoding of each antenna.

To find s_1 and s_2, we assume that CSI at the mobile stations is available. Then multiplying the received signals by the Hermitian transpose of the CSI matrix and using Maximum Likelihood (ML) concepts:

$$\hat{s}_1 = \frac{C^* \ 1y_{1a} \ + \ Q^* 1y_{2a} \ + \ D \ 2y_{1a}^* \ + \ P \ \ 2y_{2a}^*}{C^*C \ + \ Q^*Q \ + \ D^*D \ + \ P^*P} \tag{25}$$

$$\hat{s}_2 = \frac{D^* \ 1y_{1a} \ + \ P^* \ 1y_{2a} - \ C \ 2y_{1a}^* - \ Q \ 2y_{2a}^*}{C^*C \ + \ Q^*Q \ + \ D^*D \ + \ P^*P} \tag{26}$$

where $\hat{s}_u$ denote noisy version of s_u.

VI. SIMULATION RESULTS AND EVALUATION

In the present work, the signal-to-noise ratio (SNR) in comparison to the BER undergoes assessment as a precoding efficiency scale. A common MU-MIMO scheme was completed in mind of predicting the performance of the MU-MIMO beamforming precoding suggestion, alongside with the Alamouti STBC scheme over a Rician fading channel in contrast to the same scheme in the case of a Rayleigh fading channel. The parameter samples have been devised up to 10,000, encompassing elements created as zero-mean in the case of the Rayleigh fading channel, whereas for the Rician fading channel, there was the m-mean and unit-variance independently and identically distributed (i.i.d) complex Gaussian random variables. Notably, the *M* antennas of BS transmitted the signal across all users over the noise and flat fading channel, while each user employed *Nu* antennas to receive the signal. There was the application of a QPSK signal constellation as a form of broadcast modulation across all instances of simulation, with the findings then undergoing averaging through the implementation of different channel investigations. For all receivers, the noise variance per receiver antenna should be equal, $\sigma_1^2 = . . . = \sigma_K^2 = \sigma^2$. The typical values and simulation parameters are presented in Table 1.

Table 1.
Typical values and simulation parameters

Parameters	Definition
Channel type	Rayleigh and Rician
Number of users (U)	2, 3
Number of antenna for BS (M)	4, 6, 9
Number of antenna for each user (Ni)	2, 3
Rician channel factor (K)	5, 10, 15

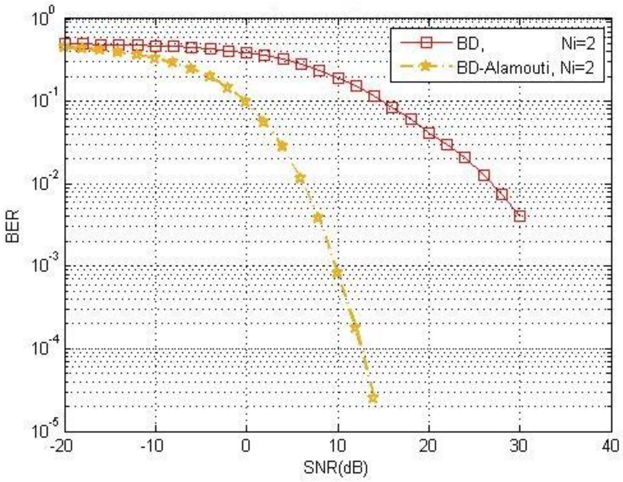

Fig. 3. A MU-MIMO system over Rayleigh channel, U = 2 and Ni=2.

As can be seen in Fig. 3, in the scenario of classical BD beamforming precoding scheme, system performance demonstrates improvement, albeit in a gradual but continuous pattern, with SNR values showing increases. While in the case of combined BD beamforming with Alamouti STBC, significant improvement could be seen at any value of SNR. In other words, the combined scheme enjoys better performance than the classical BD beamforming precoding scheme. This is because we use both BD beamforming and Alamouti STBC: for multiuser interference, we use the advantage of BD beamforming; for fading channel, we use the advantage of STBC.

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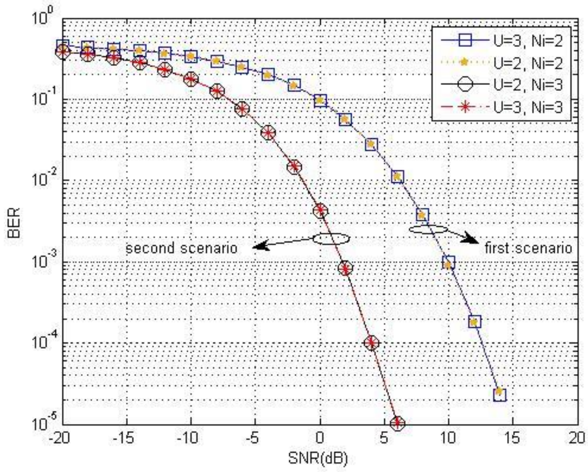

Fig. 4. A combined scheme over Rayleigh channel for different scenarios

Fig. 4 demonstrates the performance of the combined BD beamforming with Alamouti STBC scheme with different value of N_i and U. In the first scenario, each user has two receives antennas ($N_i = 2$), two cases are investigated: two users system with 4 transmit antennas at the BS; and 3 users system with 6 transmit antennas at BS. The second scenario has the extended Alamouti STBC scheme when each user has three receives antennas ($N_i = 3$), two cases are investigated: two users system with 6 transmit antennas at the BS; and 3 users system with 9 transmit antennas at BS. In Fig. 4, it is shown that the two user system achieves almost the same performance with a 3-user system in first scenario, which is consistent with our analysis in BD beamforming and Alamouti STBC. The downlink precoder completely eliminates multiuser interference at each mobile, and full spatial diversity is achieved by Alamouti codes. Similarly, in the second scenario, the two user system achieves the same performance with a 3-user system. In the second scenario higher diversity gain greatly improves the BER performance, as compared to the performance of the first scenario. Figs. 5 and 6 further show that in the LoS environment (over a correlated realistic Rician fading channel) the performance of combined system is greater when contrasted alongside the performance of the NLoS (over a Rayleigh fading channel) setting. The high value of Rician's factor has the ability to decrease error rate. To better understand the behavior of the combined scheme, the BER is plotted with different values of K to show and compare the two cases of first scenario in Fig. 5 and the two cases of second scenario in Fig. 6.

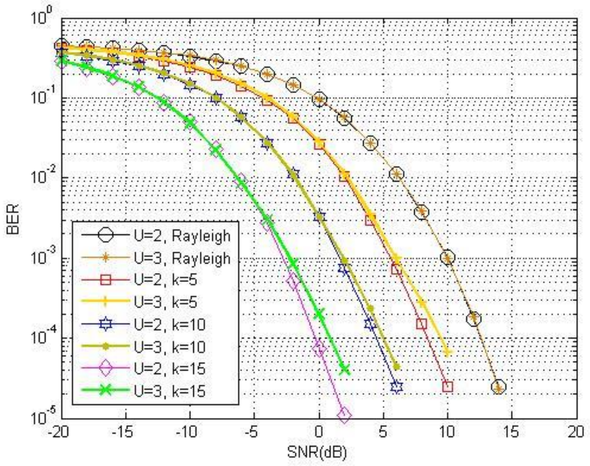

Fig.5 A MU-MIMO system employed BD precoding with Alamouti STBC in the LoS and NLoS environment with *Ni*=2.

The traditional combined beamforming with STBC have sensitive BER performance depending on the coefficient of the channel (*K*). This sensitivity of the system is also increased by increasing the value of SNR.

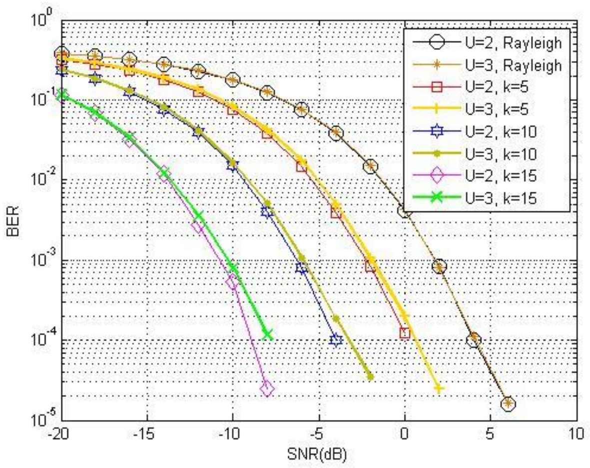

Fig. 6 A MU-MIMO system employed BD precoding with extended Alamouti STBC in the LoS and NLoS environment with *Ni*=3.

In other words, unfortunately, the desired power of the signal reception will be reduced because the BD algorithm spends some of power as leakage power, which is represented as the interference power and it does completely cancel after the transmission. Therefore, the system over wireless channel will suffer from low desired power of the received signal, impact of fading channel and noise factors. For the system over Rayleigh fading channel ($K< 0$), the number of users does not affect the performance of the system along of SNR's values because the effect of fading channel was bigger than the effect of the leakage power and noise. Therefore, the system of two users and the system of three users have same performance.

On the other hand, for the system over Ricain fading channel ($K > 0$), the low number of users does affect the performance of the system at high value of SNR because the major factor limiting the performance of the system was the leakage power and noise. Thus, over Ricain fading channel, the combined system with low number of users enjoys better performance when compared to high number of users at high SNR.

VII. CONCLUSION

This report has suggested MU-MIMO download fading channel frameworks with the implementation of pragmatic beamforming through the approach of downlink precoding, encompassing STBC system's spatial diversity. Moreover, it further provides an analysis and evaluation centred on the application of a simple BD precoding method, which is seen to entirely eradicate CCI between any and all users at the same cell location. The broadcast through the downlink MU-MIMO channel by any transmitter uses the BD beamforming algorithm to look like as the broadcast through a downlink multiple independent single-users MIMO (SU-MIMO) channel system.

Consequently, a suitable environment for the use of Alamouti STBC scheme, which works in SU-MIMO system, was provided. It can be seen, when reviewing the simulation results, that the BD precoding with Alamouti STBC scheme's BER performance is better than only BD precoding performance, because BD beamforming precoding achieves more diversity when it combines with Alamouti STBC scheme. Furthermore, an extended Alamouti STBC scheme is able to provide significant improvements in performance of a combined system. The findings further demonstrate the effect of Rician fading channel on the proposed system, which it is represented the environment of some typical of 5G application scenarios.

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