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Evaluation of Linear Precoding Schemes for Cooperative Multi-Cell MU MIMO in Future Mobile Communication Systems

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Abstract

In Mobile Communication Systems, inter-cell interference becomes one of the challenges that degrade the system's performance, especially in the region with massive mobile users. The linear precoding schemes were proposed to mitigate interferences between the base stations (inter-cell). These schemes are categorized into linear and non-linear; this study focused on linear precoding schemes, which are grounded into three types, namely Zero Forcing (ZF), Block Diagonalization (BD), and Signal Leakage Noise Ratio (SLNR). The study included the Cooperative Multi-cell Multi Input Multi Output (MIMO) System, whereby each Base Station serves more than one mobile station and all Base Stations on the system are assisted by each other by shared the Channel State Information (CSI). Based on the Multi-Cell Multiuser MIMO system, each Base Station on the cell is intended to maximize the data transmission rate by its mobile users by increasing the Signal Interference to Noise Ratio after the interference has been mitigated due to the usefully of linear precoding schemes on the transmitter. Moreover, these schemes used different approaches to mitigate interference. This study mainly concentrates on evaluating the performance of these schemes through the channel distribution models such as Rayleigh and Rician included in the presence of noise errors. The results show that the SLNR scheme outperforms ZF and BD schemes overall scenario. This implied that when the value of SNR increased the performance of SLNR increased by 21.4% and 45.7% for ZF and BD respectively.

Keywords

Precoding Schemes, Cooperative Networks, Interference, Multi-Input Multi-Output (MIMO), Multi-Cell and Multiuser

1. Introduction

The demands of today's mobile communication require higher data transmission and low delay, with mobile users sending and receiving the data with little or no interference and delay [1]. This can be achieved using a multi-input multi-output (MIMO) system in the mobile communication [2]. The MIMO systems enable linear increases in the data transmission rate with an increasing number of antennas in mobile devices and also increase the connection reliability, which contributes to the increase in performance of mobile systems [3]. However, the system can only be improved if the system throughput is increased. Nevertheless, this is becoming a significant challenge, especially in densely populated areas where mobile operators reuse the limited licensed spectrum (resources) to accommodate many users, which can lead to the higher degree of interference. This challenge requires the intensive studies for the future mobile communication systems.

Additionally, the benefits of MIMO can be enhanced during transmission if the receiver knows the information about the communication channel. The system also improved by giving the sender information about the required communication channel. This allows for exploring the idea of network collaborations. In order for the base stations (BSs) to share channel information, in particular channel state information (CSI), in order to offer services to both BSs and MSs equipped with more than one antenna, the idea of cooperation was introduced [4].

The current cooperative system in multi-cell single-user MIMO limits the system configuration in terms of the number of antennas. It allows each cell (base station) to serve only one mobile user. When the number of antennas at the transmitter exceeds the number of mobile users in a system, some spectrum resources are wasted. In addition, as the population of each cell increases, the system capacity is limited due to multi-user interference between users through multi-cell transmission [5]. Each BS on the network shares the state of a communication channel, including the precoder information. The precoding scheme reduces the interference caused by either base stations or mobile users between each other [6]. The precoded signal in each BS is transmitted to all MS with the same time slots and frequency band.

Numerous precoding schemes are proposed for Cooperative Multi-cell, linear and non-linear types. This study focuses on the linear schemes since the non-linear scheme turns out to be quite complicated compared to the linear ones, which include the Zero Forcing (ZF) Scheme, the Block Diagonalization (BD) Scheme, and the Signal Leakage and Noise Ratio (SLNR) Scheme [7]. Non-linear schemes require direct knowledge of the channel transfer function at the BS, such as the Dirty Paper Coding (DPC) Scheme is the robust precoding scheme used to mitigate cell-to-cell interferences. Conversely, linear schemes use different channel state information (CSI) degrees compared to non-linear schemes. Therefore, linear precoding schemes are easily adaptable and cheaper to implement than non-linear ones. In [8] [9] [10] [11], the authors presented a concept of BS cooperation as one of the approaches to suppress the available interference between cells (base stations). Based on the above review the study of interference on the future mobile communication system need more attention. This study evaluates the performance of three linear precoding techniques based on network and channel models regarding the average capacity rate, and signal-to-noise ratio.

2. System Model and Theoretical Descriptions

In this section, the system model of the mobile system model is addressed and the theoretical descriptions through the relationship between the transmitted signals for each precoding scheme.

2.1. System Model

Figure 1 shows the system model providing the coverage of three cells of the mobile communication system. The system is connected to a unit frequency reuse deployed at the base station and each mobile user can receive the transmitted signals from all available BSs, which are three. The signals indicated by the bold arrow are desired signals and a dotted arrow represents interference signals received from other BS.

In addition, Figure 1 demonstrates multi-cell, multi-user MIMO, where each BS is equipped with more than one antenna. A BS communicates with the group of MS users simultaneously, and each MS is equipped with an antenna. A base station uses available CSI to reduce or eliminate multi-user interference through linear precoding schemes.

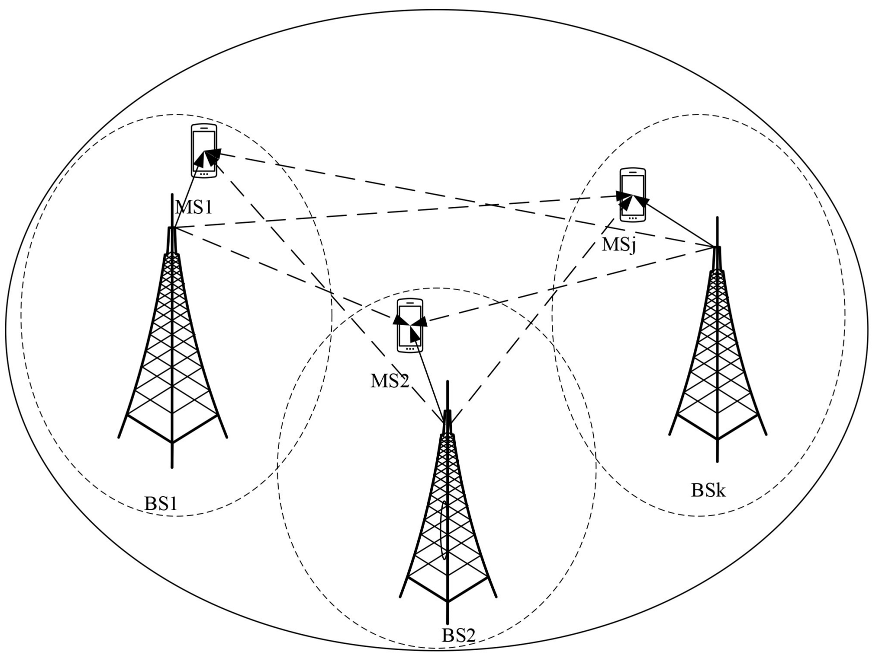

Figure 1. System model.

The three neighboring BSs establish cooperative transmission sites connected with the high-rate optical fiber in the given system model and share information such as resources, scheduling and precoding matrix. In this study, it is assumed that all base stations share the CSI. At the same time, the user information is shared with the BSs that cooperate.

2.2. Theoretical Descriptions of Model

This study uses mathematical notations, such as lower-case letters for vectors and upper-case letters for matrices. $(\cdot)^H$ stands for the Hermitian transpose, and $(\cdot)^{\mathrm{T}}$ represents the transpose matrix. $E\{.\}$ indicates the expectation operator and $N \times N$ indicates the identity matrix's size that is denoted by $\boldsymbol{I}_N$, and N represents either number of transmitting or receiving antennae.

In a Multi-Cell MU MIMO setup, each mobile station, MS is jointly served by each cooperative site of BSs that has a B number of BSs. In this system, BS has N_t a number of transmitting antennas in this system, and M mobile station has N_r a number of receiving antennas. The BSs assist each other by sharing CSI to transmit data to the available mobile station. Furthermore, each BS uses its channel to serve all the available MSs from a system, $\boldsymbol{H}_{jk}$ representing the channel matrix, which is used to connect j^{th} MS from k^{th} BS, whereby $j = 1, 2, \cdots, M$ indicate the number of MSs and $k = 1, 2, \cdots, B$ represent available BSs on the system, respectively. The value channel matrix $\boldsymbol{H}_{jk}$ used in the BS involves a number of sub-matrices, which are used to allow communication to the mobile stations and descriptions expressed as

$$\boldsymbol{H}_{jk} = \begin{bmatrix} \boldsymbol{H}_{j1} & \boldsymbol{H}_{j2} & \cdots & \boldsymbol{H}_{jB} \end{bmatrix} \tag{1}$$

From the above Equation (1) the linear precoding scheme from k^{th} BS to j^{th} MS is expressed as

$$\boldsymbol{s}_j = \boldsymbol{G}_j \boldsymbol{x}_j \tag{2}$$

where $\boldsymbol{G}_j \in C^{N_{t,j} \times 1}$ represented as precoder at BSs and $\boldsymbol{x}_j$ indicated as data symbols transmitted to j MS. Based on the cooperative BS, the j MS receives the signal from all BSs. In the system, the transmitted signals from only one BS are considered desired signals, and others are considered interfered signals. The expression of the system expressed as

$$\boldsymbol{y}_j = \sum_{k=1}^{B} \boldsymbol{H}_{jk} \boldsymbol{G}_k \boldsymbol{x}_k + \boldsymbol{n}_j \tag{3}$$

where $\boldsymbol{y}_j \in C^{N_r \times 1}$ represent the received signal and $\boldsymbol{n}_j \in C^{N_r \times 1}$ denoted as a noise vector. A noise vector is a signal modeled by zero-mean circularly symmetric complex Gaussian (ZMCSCG) with a given noise power which is equal to σ^2, hence $E\left\{\boldsymbol{n}_j \boldsymbol{n}_j^H\right\} = \sigma^2 \boldsymbol{I}_{N_r}$.

Furthermore, the equation (3) was modified by adding the noise component as

$$\boldsymbol{y}_j = \boldsymbol{H}_{jj} \boldsymbol{G}_j \boldsymbol{x}_j + \sum_{k=1, k \neq j}^{B} \boldsymbol{H}_{jk} \boldsymbol{G}_k \boldsymbol{x}_k + \boldsymbol{n}_j \tag{4}$$

where $\boldsymbol{H}_{jj} \in C^{N_{r,j} \times N_t}$ denoted as a channel matrix connecting j^{th} MS user with j^{th} BS, and $\boldsymbol{n}_j$ denoted with noise vector. From equation (4), the expression $\boldsymbol{H}_{jj}\boldsymbol{G}_j\boldsymbol{x}_j$ represents the desired signals and $\sum_{k=1,k\neq j}^{B} \boldsymbol{H}_{jk}\boldsymbol{G}_k\boldsymbol{x}_k + \boldsymbol{n}_j$ the interference that occurred on Multi-cell Multiuser. Furthermore, the component $\{\boldsymbol{H}_{jk}\boldsymbol{G}_k\}$ represents the j^{th} MS and k^{th} BS channel matrix.

From the equations above, the total amount of power applied to the j^{th} MS user at the transmitter expressed as

$$P_j = E\left\{\left(\boldsymbol{G}_j\boldsymbol{x}_j\right)^H \boldsymbol{G}_j\boldsymbol{x}_j\right\} = \beta^2 tr\left(\boldsymbol{G}_j^H\boldsymbol{G}_j\right) \tag{5}$$

whereby β represents the received data having the same power and let $\beta^2 = 1$ represent $E\left[\left|\boldsymbol{x}_j\right|^2\right]$ data symbols transmitted to j MS and $tr\left(\boldsymbol{G}_j^H\boldsymbol{G}_j\right) = 1$ whereby $\boldsymbol{G}$ is normalized. In simplicity, the amount of the data received equals the number of receiving antennae equal to one [12]. The matrix $\boldsymbol{G}_j$ satisfies the condition whereby the interference is equal to zero.

2.3. Implementation of Precoding Schemes

To design the precoding matrix in the MU-MIMO scenario as in a SU-MIMO, the interference in MU-MIMO is suppressed by reducing the overlap of row vector spaces in channel matrices. A row vector space spanned by different users through effective channel matrices and MIMO processing gain requires mobile users to use the available subspaces. The precoder matrix preserved complex elements and added redundancy to the input symbol streams to improve system performance [13].

The precoder output is launched into the MIMO channel through N_t transmit antennas. The signal is received by N_r receiving antennas and processed by the linear decoder optimized by the fixed and known channel. The linear decoder also operates in the complex domain and removes any redundancy introduced by the precoders. Figure 2 below shows a flow block of a linear precoder system when the signals are coded. The signals are transmitted via the communication channel, and at the receiver, the signals are decoded for retained the original signals. The three linear precoding schemes ZF, BD and SLNR are discussed and described in detail following subsections.

2.3.1. Zero Forcing Precoding

The zero forcing Precoding is considered one of the spatial signal processing in which multiple transmitting antennas can nullify the interference of signals for

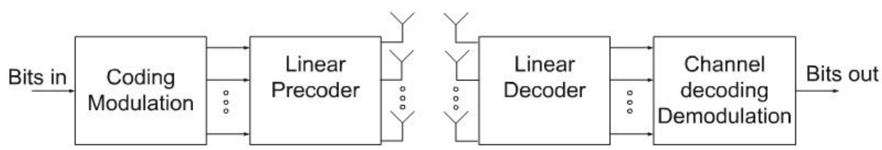

Figure 2. Linear precoder system block.

the multi users in the communications system [14] by applying the channel inverter at the BSs. The distributed ZF Precording scheme is derived for the received signal at which every user terminal on the mobile systems is coordinated [15]. However, the base station does not influence the noise of mobile users.

The scheme is sometimes observed as a multiuser decorrelator, which uses a pseudo-inverse of the channel matrix on the system as defined as $\boldsymbol{H}_{jk} = \left[\boldsymbol{H}_{j1}^{\mathrm{T}} \quad \boldsymbol{H}_{j2}^{\mathrm{T}} \quad \cdots \quad \boldsymbol{H}_{jB}^{\mathrm{T}}\right]^{\mathrm{T}}$, the ZF precoding scheme is expressed as

$$\boldsymbol{P} = \boldsymbol{H}_{jk}^{H}\left(\boldsymbol{H}_{jk}\boldsymbol{H}_{jk}^{H}\right)^{-1} \tag{6}$$

Then finally, the precoder is chosen from the normalized columns of the channel matrix, which is defined in the equation;

$$\boldsymbol{G}_j = \frac{\boldsymbol{P}}{\left(\left(\boldsymbol{H}_{jk}\boldsymbol{H}_{jk}^{H}\right)_{j,j}^{-1}\right)^{\frac{1}{2}}},\ j = 1, 2, \cdots, M \tag{7}$$

After the precoder is obtained and applied at the transmitter side, all the interference that occurs at the mobile user terminals will be eliminated. However, the transmitter (BSs) does not influence the noise in the user terminal. Therefore, the ZF suffers from noise problem that requires increasing transmit power. This results in significant degradation of the performance of the Mobile Systems.

2.3.2. Block Diagonalization

Block Diagonalization (BD) becomes one of the linear precoding techniques used to cancel the interferences in MU-MIMO systems through the downlink communication [16].

The interference cancellation using BD is applied through the consideration of orthogonality in the channel matrix of each user, which means the interfered signals are projected onto the complementary subspace of the spanned on the desired signal of the channel matrix corresponding to the user followed by the SVD approach [17]. Then, the channel matrix of mobile user *j* from all BSs defined as

$$\tilde{\boldsymbol{H}}_j = \left[\boldsymbol{H}_{j1} \quad \boldsymbol{H}_{j2} \quad \cdots \quad \boldsymbol{H}_{jB}\right] \tag{8}$$

Then from the equation above precoder is determined by considering the channel matrix from all users instead of only user *j* as defined $\bar{\boldsymbol{H}}_j \in C^{(M-1)N_r \times N_t}$

$$\bar{\boldsymbol{H}}_j = \left[\tilde{\boldsymbol{H}}_1^{\mathrm{T}} \quad \cdots \quad \tilde{\boldsymbol{H}}_{j-1}^{\mathrm{T}} \quad \tilde{\boldsymbol{H}}_{j+1}^{\mathrm{T}} \quad \cdots \quad \tilde{\boldsymbol{H}}_M^{\mathrm{T}}\right]^{\mathrm{T}} \tag{9}$$

The principle of the block diagonalization scheme is to find the Precoding matrix to fulfill the constraint $\bar{\boldsymbol{H}}_j\boldsymbol{G}_k = 0$ for the user $j \neq k$. It implies that all the interference is eliminated and $\bar{\boldsymbol{H}}_j$ represents the channel matrix of the entire user terminal other than user *j*. For the inter-use interference to be reduced to zero, the $\boldsymbol{G}_j$ must lie in the null space $\bar{\boldsymbol{H}}_j$, which occurs at the moment the number of all transmitting antennas is not smaller than all the number of receiving antennas. Then, $\bar{\boldsymbol{H}}_j$ it can be expressed using singular value decomposition (SVD), which takes the rectangular matrix with the rank of $\bar{L}_j$ and also the SVD interprets an expansion of the original data in a coordinate system in which the covariance matrix is diagonal; hence the expression becomes

$$\bar{\boldsymbol{H}}_j = \bar{\boldsymbol{U}}_j \begin{bmatrix} \bar{\Sigma}_j & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \bar{\boldsymbol{V}}_j^{(1)} & \bar{\boldsymbol{V}}_j^{(0)} \end{bmatrix}^H \quad (10)$$

The symbol $\bar{\Sigma}_j$ denotes a diagonal matrix with singular values of the $\bar{\boldsymbol{H}}_j$ to be its diagonal elements with a dimension equal to that channel matrix's rank. $\bar{\boldsymbol{V}}_j^{(1)}$ and $\bar{\boldsymbol{V}}_j^{(0)}$ indicates the singular vectors related to the nonzero and zero singulars, which hold first $\bar{L}_j$ and last $N_t - \bar{L}_j$ of the right singular vectors, respectively. From $N_t - \bar{L}_j$ singular vectors indicated a last right, which expressed as $\bar{\boldsymbol{V}}_j^{(0)} \in C^{N_t \times (N_t - \bar{L}_j)}$ and produced an orthogonal basis of a null space of the channel matrix $\bar{\boldsymbol{H}}_j$ that eliminates the multiuser interference. Then, after determining $\bar{\boldsymbol{V}}_j^{(0)}$ the effective channel matrix in SVD can be expressed as

$$\tilde{\boldsymbol{H}}_j \bar{\boldsymbol{V}}_j^{(0)} = \bar{\boldsymbol{U}}_j \begin{bmatrix} \bar{\Sigma}_j & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \boldsymbol{V}_j^{(1)} & \boldsymbol{V}_j^{(0)} \end{bmatrix}^H \quad (11)$$

The dimension of $\tilde{\boldsymbol{H}}_j \bar{\boldsymbol{V}}_j^{(0)}$ is expressed as $N_r \times (N_t - \bar{L}_j)$ indicated on the system, and also the product of $\bar{\boldsymbol{V}}_j^{(0)}$ and $\boldsymbol{V}_j^{(1)}$ produces the orthogonal basis. This produces the precoders matrix for user *j* as expressed in the equation below;

$$\boldsymbol{G}_j = \begin{bmatrix} \bar{\boldsymbol{V}}_1^{(0)} \times \boldsymbol{V}_1^{(1)} & \bar{\boldsymbol{V}}_2^{(0)} \times \boldsymbol{V}_2^{(1)} & \cdots & \bar{\boldsymbol{V}}_M^{(0)} \times \boldsymbol{V}_M^{(1)} \end{bmatrix} \quad (12)$$

Hence for the different users, the precoders can be further simplified as

$$\boldsymbol{G}_j = \begin{bmatrix} \boldsymbol{G}_1 & \boldsymbol{G}_2 & \cdots & \boldsymbol{G}_M \end{bmatrix} \quad (13)$$

The expression shows that the precoder matrix $\boldsymbol{G}_j$ and the effective channel form the block diagonal, which implies that the interference is eliminated and results in maximizing the sum capacity of the system due to the increased SINR.

2.3.3. Signal to Leakage and Noise Ratio

The SLNR precoder is one of the linear precoders designed for multiuser MIMO systems to maximize the strength of the desired signal relative to the nose and overall interference caused by the other users [18]. Compared to the BD precoder, the SLNR has no limitation on the number of transmit antennas at the base station, which is suitable for any number of users and data streams. In general, the SLNR evaluates the linear precoding weights determined by the generalized eigenvalue decomposition of the channel matrix and leakage channel plus noise matrix of a given user [19].

Based on the original SLNR precoding scheme [20] the SLNR is defined as the ratio of the power of the desired signal received at MS to the power of the received signal from the other terminals or leakage plus the power of the noise from the scenario SLNR for the mobile user *j* can be expressed by the following questions;

$$\begin{aligned} \text{Desired power} &= E\left[\left(\boldsymbol{H}_{jj} \boldsymbol{G}_j \boldsymbol{x}_j \right)^H \left(\boldsymbol{H}_{jj} \boldsymbol{G}_j \boldsymbol{x}_j \right) \right] \\ &= \alpha^2 tr\left[\left(\boldsymbol{H}_{jj} \boldsymbol{G}_j \right)^H \left(\boldsymbol{H}_{jj} \boldsymbol{G}_j \right) \right] \end{aligned} \quad (14)$$

$$\begin{aligned}\text{Leakage power} &= E\left[\sum_{k=1,k\neq j}^{B}\left(\boldsymbol{H}_{jk}\boldsymbol{G}_j\boldsymbol{x}_j\right)^H\sum_{k=1,k\neq j}^{B}\left(\boldsymbol{H}_{jk}\boldsymbol{G}_j\boldsymbol{x}_j\right)\right] \\ &= \alpha^2\sum_{k=1,k\neq j}^{B} tr\left[\left(\boldsymbol{H}_{jk}\boldsymbol{G}_j\right)^H\left(\boldsymbol{H}_{jk}\boldsymbol{G}_j\right)\right]\end{aligned} \tag{15}$$

In the above equations, the SLNR is described in the expression below according to its definition;

$$\begin{aligned}SLNR_j &= \frac{\alpha^2 tr\left[\left(\boldsymbol{H}_{jj}\boldsymbol{G}_j\right)^H\left(\boldsymbol{H}_{jj}\boldsymbol{G}_j\right)\right]}{\alpha^2\sum_{k\neq j} tr\left[\left(\boldsymbol{H}_{jk}\boldsymbol{G}_j\right)^H\left(\boldsymbol{H}_{jk}\boldsymbol{G}_j\right)\right]+N_r\sigma^2} \\ &= \frac{\alpha^2 tr\left[\boldsymbol{G}_j^H\boldsymbol{H}_{jj}^H\boldsymbol{G}_j\boldsymbol{H}_{jj}\right]}{\alpha^2\sum_{k=1,k\neq j}^{B} tr\left[\left(\boldsymbol{H}_{jk}\boldsymbol{G}_j\right)^H\left(\boldsymbol{H}_{jk}\boldsymbol{G}_j\right)\right]+N_r\sigma^2} \\ &= \frac{tr[\boldsymbol{G}_j^H\boldsymbol{H}_{jj}^H\boldsymbol{G}_j\boldsymbol{H}_{jj}]}{tr\left[\sum_{k=1,k\neq j}^{B}\left(\boldsymbol{G}_j^H\boldsymbol{H}_{jk}^H\boldsymbol{G}_j\boldsymbol{H}_{jk}\right)\right]+N_r\sigma^2/\alpha^2}\end{aligned} \tag{16}$$

In this scheme, we assume that each user received the signal from the transmitter with equal power [20]. For simplicity, the expressions can be reduced as $\boldsymbol{A}_j = \boldsymbol{H}_{jj}^H\boldsymbol{H}_{jj}$, and $\boldsymbol{B}_j = \sum_{k=1,k\neq j}^{B}\boldsymbol{A}_k + N_r\delta^2/\alpha^2$, whereby $\boldsymbol{A}_k = \boldsymbol{H}_{jk}^H\boldsymbol{H}_{jk}$.

The final expression will be expressed as

$$SLNR_j = \frac{tr\left[\boldsymbol{G}_j^H\boldsymbol{A}_j\boldsymbol{G}_j\right]}{tr\left[\boldsymbol{G}_j^H\boldsymbol{B}_j\boldsymbol{G}_j\right]} \tag{17}$$

The precoder $\boldsymbol{G}_j$ in Equation (17) intended to maximize the value of $SLNR_j$ by assumed that the receiver receives only single data stream. Then, the $\boldsymbol{B}_j$ and $\boldsymbol{A}_j$ matrices used to generalize the eigen-value through the eigen-vectors. Finally, the value of precoder is determined by considering the maximum eigen-vector of the produdut $\boldsymbol{B}_j^{-1}\boldsymbol{A}_j$ [21].

By determining the value of eigenvector existed from nonzero vector, then the expression of Precoding is expressed as

$$\boldsymbol{G}_j = eign\left(\boldsymbol{B}_j^{-1}\boldsymbol{A}_j\right) \tag{18}$$

From the equation above, maximum eigenvalue describes best precoder represented by SLNR scheme used on the transmitter side to increase the capacity rate at the receiver by reducing interference [22].

2.3.4. Receiver Processing

The transmitted signal arrived at the receiver at different paths due to propagation effect known as multipath effect, which caused the signals distortion. Therefore, at the receiver MMSE detection method is deployed to detect desired signals and remove unwanted signals.

By considering each scheme, an effective estimated channel is expressed as $\boldsymbol{H}_{eff,j} = \boldsymbol{H}_{jj}\boldsymbol{G}_j$, the expression of the received signal defined as

$$\tilde{\boldsymbol{y}}_j = \boldsymbol{W}_{\boldsymbol{G}_j}^H \boldsymbol{y}_j \tag{19}$$

From the equation above, the received signal can further express toward

$$\tilde{\boldsymbol{y}}_j = \boldsymbol{W}_{\boldsymbol{G}_j}^H \left(\boldsymbol{H}_{jj} \boldsymbol{G}_j \boldsymbol{x}_j + \sum_{k=1,k\neq j}^{B} \boldsymbol{H}_{jk} \boldsymbol{G}_k \boldsymbol{x}_k + \boldsymbol{n}_j \right) \tag{20}$$

Based on the expression above, the MMSE for detection of the received can be described through the equation below;

$$\boldsymbol{W}_{\boldsymbol{G}_j} = \boldsymbol{G}_j^H \boldsymbol{H}_j^H \left(\sigma^2 \boldsymbol{I}_{N_r} + \boldsymbol{H}_{eff,j} \boldsymbol{H}_{eff,j}^H \right)^{-1} \tag{21}$$

Then SINR on the system is expressed as

$$SINR_j = \frac{E\left\{ \left\| \boldsymbol{W}_{\boldsymbol{G}_j} \boldsymbol{H}_{jj} \boldsymbol{G}_j \boldsymbol{x}_j \right\|^2 \right\}}{E\left\{ \left\| \boldsymbol{W}_{\boldsymbol{G}_j} \sum_{k=1,k\neq j}^{B} \boldsymbol{H}_{jk} \boldsymbol{G}_k \boldsymbol{x}_k + \boldsymbol{W}_{\boldsymbol{G}_j} \boldsymbol{n}_j \right\|^2 \right\}} \tag{22}$$

The equation (22) represents the SINR of a mobile user, which is expressed in terms of the Precoding Scheme. The expression shows when the interference reduces the SINR maximized. It improves the sum rate or capacity rate of the system, which expressed as

$$R_{sum} = \sum_{j=1}^{M} \log_2 \left(\det \left(1 + SINR_j \right) \right) \tag{23}$$

Therefore, this study uses the expression to evaluate the performance of ZF, BD, and SLNR precoder schemes.

3. Numerical Analysis and Evaluation

In this section, explain the analysis and evaluation of the three precoding Schemes. The results are described in two aspects: the first one on channel distribution model for the Rayleigh, and Rician distribution which is deployed at receiver side and impact of the errors in given Channel State Information.

3.1. Channel Distribution Models

This study uses the Gaussian random channel that includes two models, the Rayleigh, and Rician distributions. Both distributions are subjected to either Line of sight (LOS) or Non-line of sight (NLOS). The channel matrix of $\boldsymbol{H}_{jk}$ between transmitter and receiver is obtained using real, and imaginary variables at a given zero mean, and equal variance. Furthermore, we assumed the $\boldsymbol{U}_{jk}$ is a normalized channel of $i.i.d\ \ CN(0,1)$ matrix. Then the channel matrix of each distribution expressed as

$$\text{Rayleigh distribution: } \boldsymbol{U}_{jk} = \boldsymbol{H}_{jk} \tag{24}$$

$$\text{Rician distribution: } \boldsymbol{U}_{jk} = \sqrt{\frac{K}{1+K}} \boldsymbol{H}_{jk}^{LOS} + \frac{1}{\sqrt{1+K}} \boldsymbol{H}_{jk} \tag{25}$$

In Equation (25), K denoted as the value of the rician factor defined as the ratio of a power of channel at LOS component with the power of the scattered component. This is obtained as $K \to -\infty$ dB to the pure LOS aat $K \to +\infty$ dB [23]. Furthermore, the when value of $K = 0$ dB the channel is considered as Rayleigh fading and when value pf $K \to \infty$ channel is non-fading channels. The channel matrix H_{jk}^{LOS} of LOS is assumed as a deterministic matrix with rank [24].

3.2. Impact of Channel State Information on the System

From the above schemes, the assumption is made that the transmitter knows CSI. This is incurred through reverse channel estimation in time-division- duplex (TDD) or feedback in frequency-division-duplex (FDD) [25].

Fortunately, in the above consideration at the receiver, CSI is assumed to be perfect and an error-free feedback link. However, it is impossible for the channel to perfect due to errors during the transmission between the transceivers [26].

This section addresses the impact of the errors in the Precoding Schemes. The expression of the channel state information with estimated errors expressed as

$$\hat{\boldsymbol{H}}_{jk} = \boldsymbol{H}_{jk} + \boldsymbol{E}_{jk} \tag{26}$$

where $\hat{\boldsymbol{H}}_{jk}$ denoted as actual channel matrix and $\boldsymbol{H}_{jk}$ represents as zero-mean complex Gaussian random matrix of a real channel. $\boldsymbol{E}_{jk}$ indicated as an additive error component that follows *i.i.d* complex Gaussian distribution, which has zero mean and variance of mutually independent presented as $\boldsymbol{E}_{jk} \sim CN\left(0, \sigma_e^2\right)$. Furthermore, from Equation (26) the error component is added and accounted as noise obtained from channel estimated error [27]. The desired and interference components remain the same, hence the linear precoding schemes that cancel the interference term.

3.3. Evaluation and Discussion of Results

The results were obtained by conducting the simulation through Matlab, and analyses were made by comparing the performance of the three schemes in variation of average capacity rate in bits/sec/Hz, and the signal-to-noise ratio in (dB). The parameters used in this study are summarised in **Table 1**.

Through the simulation, the individual scheme obtained the results and presented on the graphs. The performance per each scheme discussed is founded on the changes in average capacity rate with the signal-to-noise ratio. Additionally,

Table 1. Parameters used in the simulation.

S/N	Attributes	Value
1	Mobile Users, M	3
2	Cells (Base Stations), B	3
3	Number of antennae for Mobile User, N_r	1
4	Number of antennae for Base Station, N_t	4
5	Rician Factor, K	[−10, 10] dB
6	Estimated error, vr	[0.3, 0.5]

each scheme is generalized using a unique attributes such as eigenvalue, channel inversion, precoder matrix for the SLNR, the ZF, and the BD scheme respectively.

During the simulation, the value of rician factor was set to be −10 dB. The results shown in Figure 3 indicate that the SLNR precoding scheme offers better performance compared to ZF and BD schemes in both channel distribution models. Furthermore, as the value of SNR increases the performance of each scheme is almost equal for both distributions. This is because the value of the Rician factor approaches zero, which implies that the channel distribution is considered as a Rayleigh model and the radio frequency propagation in the bands is more reliable under NLOS than under LOS conditions.

The results in Figure 4 show that SLNR performs better than ZF and BD at all SNR values. Also, the standard Rayleigh distribution performs better than the

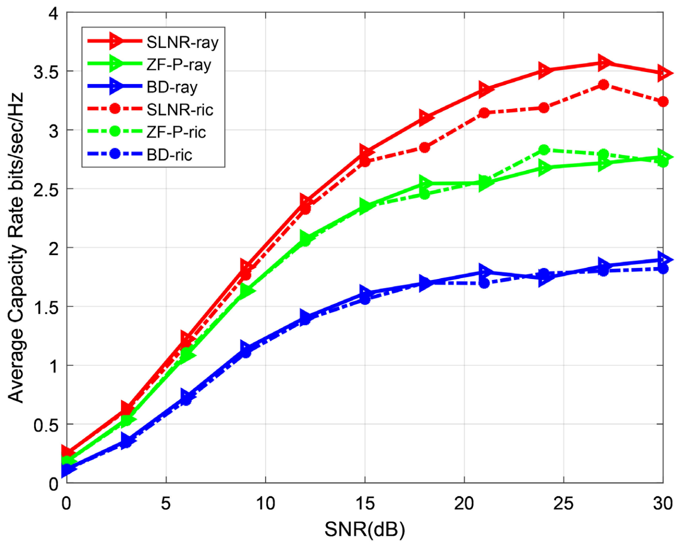

Figure 3. Variation of three Precoding schemes at $K = -10$ dB.

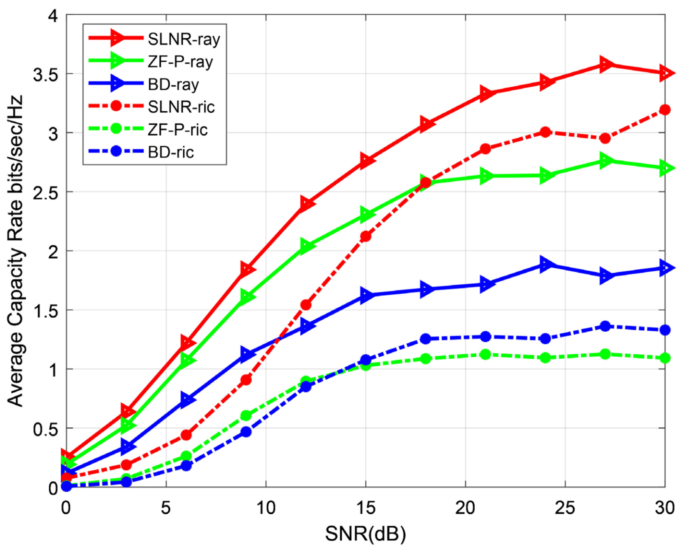

Figure 4. Variation of three Precoding schemes at $K = 10$ dB.

Rician distribution in all SNR values, which means that the Rician distribution is about the same as the Gaussian distribution around the mean. This implies that random multipath components arriving at different angles are superimposed on a stationary dominant signal. The two figures showed that when the SNR value is small, an average capacity rate becomes so scarce compared to the high SNRs, because the number of transmitted antennas is larger than the received signal on the system, which receives multiple signals due to multipath transmission from the transmitter.

The CSI at a small value of SNRs in the MIMO systems mostly follows the idea of multiplicative increases in the average capacity rate. On the other hand, when the SNR value is high, the capacity rate increases according to the additive idea in a system where the number of transmitting antennas is larger than that of receiving antennas. In this scenario, the optimal input is subjected to the CSI on the transmitter side.

Figure 5 shows that SLNR performance is better than ZF and BD. However, BD is also better than ZF because ZF removes all interference from the mobile user. In addition, the performance of all schemes is reduced due to the presence of estimation errors. In this case, when the estimation error variance becomes small, the average capacity rate decreases as the value of SNR increases.

Figure 6 shows the result obtained when the variance of the estimation error is equal to 0.5. The presence of the error implies that the received signals are affected and the average capacity rate decreases as the value of SNRs increases. In addition, the SLNR precoding scheme has better performance compared to ZF and BD for both distributions. In addition, the graph shows that the SLNR scheme suffered more as the estimation error variance increased. As the reference SNR increases, the interference between the mobile users becomes more significant compared to the thermal noise of the receiver.

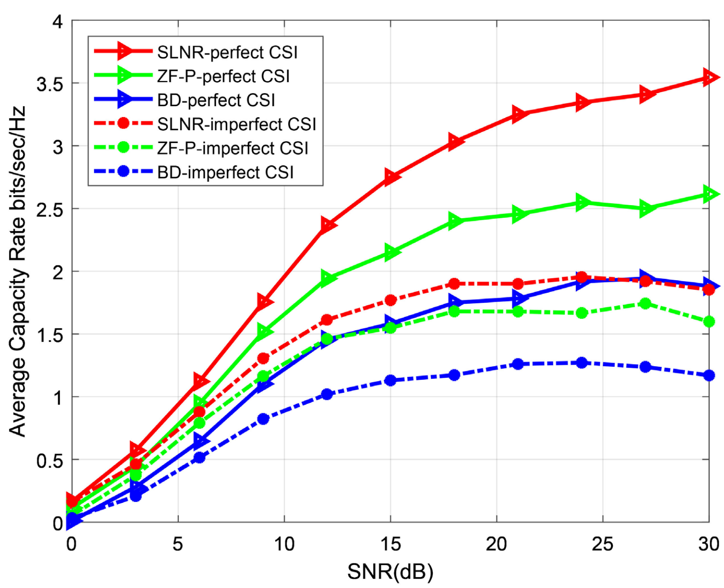

Figure 5. Variation of three Precoding schemes at $vr = 0.3$.

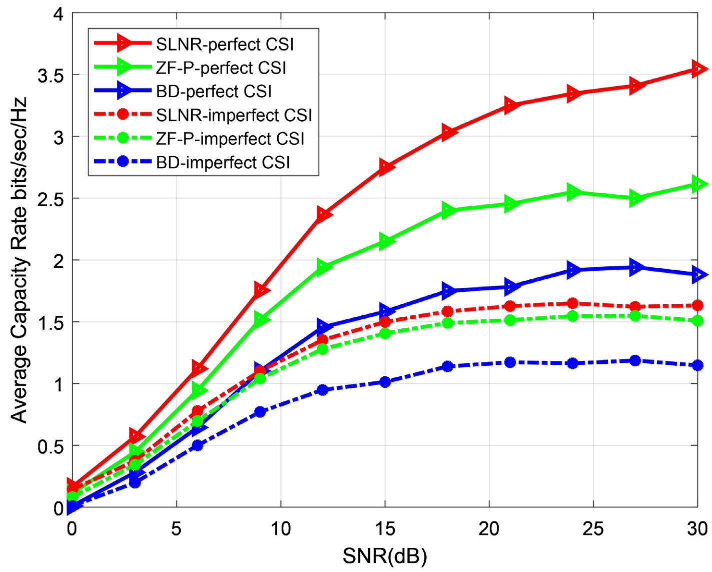

Figure 6. Variation of three Precoding schemes at $vr = 0.5$.

Subsequently, mitigating such interference by a cooperative multi-cell MIMO system becomes more valuable for system performance. In addition, system performance can be improved when using the channel estimation approach. Channel estimation is used by combining the orthogonal symbols at the beginning of the frame as a pilot or using a training sequence to estimate the value of both the transmitter (BS) and receiver (MS) channel state information (CSI).

4. Conclusions

This study discusses the impact of inter-cell interference on 5G mobile communication systems. The study considered the scenario where the base stations cooperate by exchanging the channel state information. Three precoding schemes were investigated, including Zero Forcing (ZF) Precoder, Block Diagonalization (BD) Precoder, and Signal Leakage Noise Ratio (SLNR) to mitigate the interference. The proposed schemes are evaluated by the Rayleigh and Rician channel distribution models by analyzing the performance due to imperfect channel state information. The result shows that the SLNR scheme outperforms ZF and BD schemes. This implied that the future mobile communication systems can be integrated the SLNR technique to improve the average capacity rate by reducing the impact of the interferences on the systems.

In this study, we consider the base station to serve only one mobile user at time but in the future can be modified to the more than one user and the evaluation performance will be based on the heterogenous 5G mobile communication system for Machine Type Communication and IoT devices.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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