Performance of Leakage Based Precoding Scheme for Minimizing Interference

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Abstract**—**In this paper, we consider the performance of leakage based linear precoding scheme in downlink multiuser MIMO. This work focuses on minimizing the interference to improve the performance system. The proposed leakage based linear precoding will be investigated in term of bit error rate (BER), sum rate capacity and outage. Simulation results show that the leakage based linear precoding scheme (MMSE SLNR and BD SLNR) achieved better BER, higher sum rate capacity, and lower outage than non-leakage precoding scheme (BD). At specific 10 dB SNR, there are 2.3 10^{-3} and 1.8 10^{-2} of target BER for MMSE SLNR and BD SLNR, respectively. Furthermore, the MMSE SLNR yields a lower outage than BD SLNR, at specific 2 dB SINR, the probability of an outage is 0.65 for MMSE SLNR and 0.86 for BD SLNR. Overall, the MMSE has better performance than BD SLNR because it has capabilities to eliminate the IUI and ISI.

Index Terms**—**Leakage based precoding, MMSE SLNR, BD SLNR, BER-outage, sum-rate

I. INTRODUCTION

Nowadays, mobile communication technology is moving into the fifth generation which can provide a gigabit data rate communication. One of the most important subsystems of the fifth mobile communication technology is the antenna subsystem, to support a gigabit data rate service, the fifth mobile communication technology applies a MIMO antenna system (multiple input multiple output). The MIMO antenna system has attracted attention due to its capability of improving link reliability and increasing data rate without extra power transmit and bandwidth. The number of user in mobile communication service is now increasing exponentially, a billion devices are connected through the mobile communication network. Multiple antennas are mounted at a single transmitter to serve multiple users (receivers) simultaneously. Early MIMO was addressed on SU MIMO (single-user MIMO) where the multiple spatial channels were used for a single user. Now, research focused on MU MIMO (multi-user MIMO) where multiple users were served simultaneously in the same frequency and time slot, it is shown in Fig. 1. MU MIMO increased significantly the spectral efficiency. Recently, the number antenna at the transmitter transforms into a large number antenna, it is usually called a massive MIMO. In term of multi-user MIMO that means the massive MIMO serves multiple users with a single or multiple receiver antenna. In multi-user MIMO, the transmitters serve several users in the same time slot and frequency that means the presence of multiple users cause interference in downlink multi-user MIMO system, the channel of downlink multi-user MIMO is depicted in Fig. 2. Several types of interference that arise in downlink multi-user MIMO: inter-user interference (ISI), inter-cell interference (ICI), and co-channel interference (CCI). The existence of noise and interference influences the performance of downlink massive MIMO. Interference will degrade the capacity and bit error rate of the downlink multi-user MIMO system. The elimination or suppression of the interference and noise can be accommodated by providing decoding at the receiver and precoding scheme at the transmitter. However, decoding at the receiver in the downlink MU MIMO system caused increasing of computational complexity. Generally, precoding schemes at transmitter were categorized into two types: nonlinear and linear precoding system. DPC (dirty paper coding) and Tomlison–Harashima precoding are categorized into nonlinear precoding [1]-[11]. The nonlinear precoding yielded high sum rate capacity with higher computational complexity. The linear precoding, such as block diagonalization (BD), minimum mean square error (MMSE), and zero-forcing (ZF) had a moderate sum rate capacity with lower computational complexity. In addition, several criterions of precoding schemes have been developed and proposed to handle the interference and noise, i.e., interference ignorant, orthogonal filtering, orthogonal precoding, leakage based precoding, minimal interference precoding, maximum interference precoding algorithm, and an iterative scheme [1], [9].

In previous work [2], zero-forcing (ZF) precoding scheme eliminated the co-channel interference but neglected the noise. The zero forcing brings a constraint in term of the number of transmit antennas, particularly the number of antennas in the transmitter must be larger than the number of antennas in the receiver. The work [3] investigated the performance of block diagonalization which effectively suppressed the intra-cell interference. In addition, the authors in [4] investigated the performance of whitening filter in BD precoding scheme

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to enhance intracell interference suppression. In [5], [12], the MMSE was adopted to investigate the MIMO interference channel due to the throughput was formulated as a function of MMSE under total transmit power constraint. Signal to interference plus noise ratio (SINR) precoding scheme, the authors in [2] showed that the SINR eliminated the interference and reduced the noise, however it had higher computational complexity and difficult to implemented in practice. Signal to leakage plus noise ratio (SLNR) precoding scheme could eliminate the interference and noise simultaneously whereas the comparison of signal to interference is illustrated in Fig. 4. In the SLNR precoding scheme, the leakage refers to the interference appears on the other undesired users from a transmitted signal for the specific desired user as depicted in Fig. 3. In other words, it can be defined as how much transmitted signal leaks into the other undesired users in downlink MU MIMO. The performance criteria of SLNR precoding coefficients based on optimizing the signal-to-noise plus leakage ratio for all users. The SLNR is also independent of the restriction in term of the number of transmitting and receiving antennas.

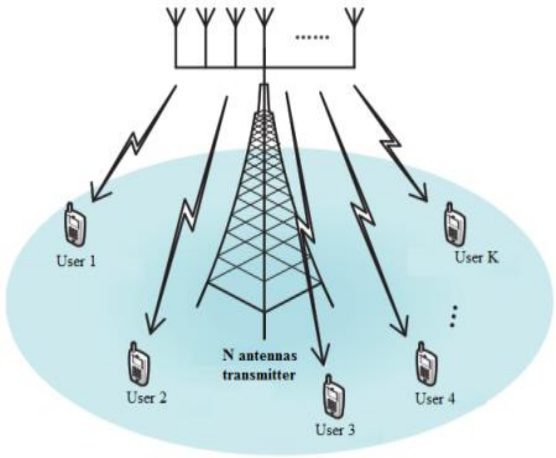

Fig. 1. Downlink multi-user MIMO [6]

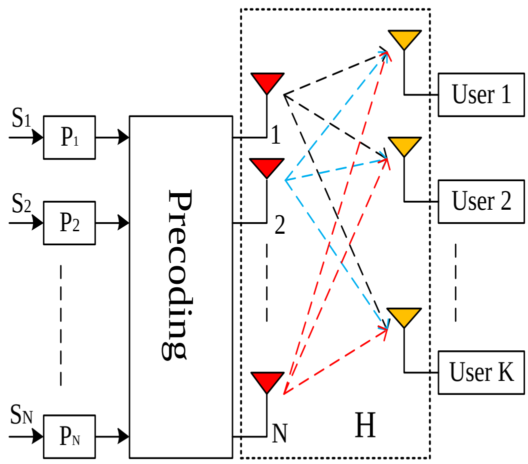

Fig. 2. Multi-user MIMO channel

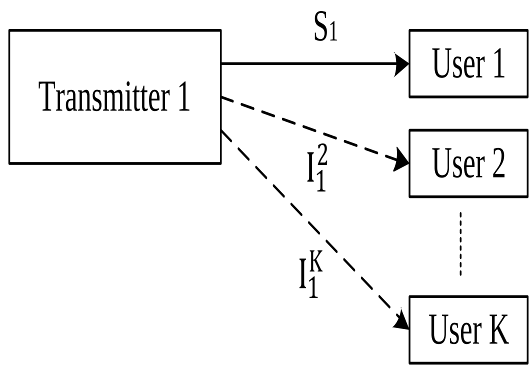

Fig. 3. Signal and interference leakage for a single transmitter [7]

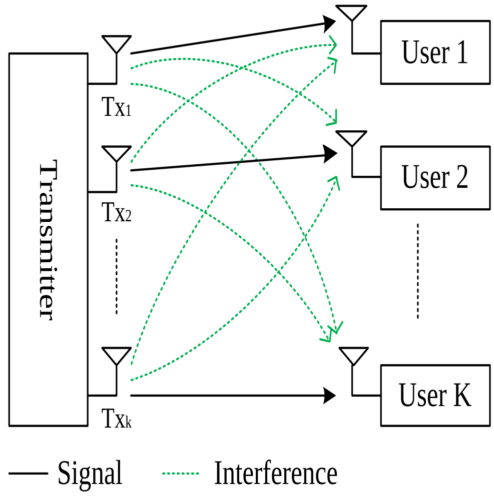

Fig. 4. Signal and Interference of K-user MIMO channel model

This paper is addressed to investigate the performance of leakage-based linear precoding scheme in term of bit error rate and sum-rate capacity. We consider BD-SLNR and MMSE-SLNR precoding scheme. The remainder of this paper is divided into four sections, section II describes the system model of leakage-based linear precoding scheme. Section III delivers the numerical results of sum rate capacity, outage system, and bit error rate (BER) parameters. The last, section IV concludes the performance of leakage-based precoding scheme.

II. SYSTEM MODEL

We consider the system model of multi-user MIMO in Fig. 5, a single transmitter serves the K users. The transmitter is completed with M transmit antennas, while each user is assumed to employ a single antenna. As depicted in Fig. 5, the received signal at the kth user can be formulated as follows,

$$Y_k = h_k w_k s_k + \sum_{j=1, j\neq k}^{K} h_k w_j s_j + n_k \qquad (1)$$

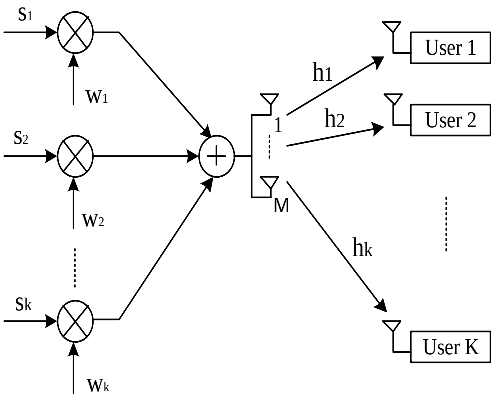

Fig. 5. A model system of downlink multiuser MIMO

where $\mathbf{S_k}$ represents an information signal of user k and normalized $\mathbf{E\{|S_k|^2\} = 1}$, w_k is M x 1 precoding vector and normalized $\|\mathbf{w_k}\|_2^2 = \mathbf{1}$, h_k is a channel vector that this is formed between M transmit antennas in the transmitter and user k. n_k denotes the additive white gaussian noise (AWGN) at user k with variance $\boldsymbol{\sigma_k^2}$. We assumed that each user had the same ratio of transmit signal to noise, i.e. $\mathbf{E\{|S_k|^2\}}/\boldsymbol{\sigma_k^2}$, so that the signal to interference plus noise ratio (SINR) of k^{th} user (SINR) can be expressed as [8],

$$\mathrm{SINR_k} = \frac{\|h_k w_k\|^2}{M_k\sigma_k^2 + \sum_{j=1,j\neq k}^{K}\|h_k w_j\|^2} \tag{2}$$

The leakage–based criterion from (2), the desired signal for user k is denoted by $\|h_k w_k\|^2$ while the raised interference by user k on some undesired user is given by $\|h_k w_j\|^2$. The leakage signal of user k is the accumulation of transmit power leaked by user k to all undesired other users.

$$\sum_{j=1,j\neq k}^{K}\|h_j w_k\|^2 \tag{3}$$

Referring to the concept of SINR in (2). The SLNR solution consists of signal power, noise, and leakage power. The signal power, $\|h_k w_k\|^2$, is expected to be larger than the noise, $M_k\sigma_k^2$, and the leakage power $\sum_{j=1,j\neq k}^{K}\|h_j w_k\|^2$.

$$\mathrm{SLNR_k} = \frac{\|h_k w_k\|^2}{M_k\sigma_k^2 + \sum_{j=1,j\neq k}^{K}\|h_j w_k\|^2} \tag{4}$$

$$\mathrm{SLNR_k} = \frac{\|h_k w_k\|^2}{M_k\sigma_k^2 + \|\tilde{h}_k w_k\|^2} \tag{5}$$

The objective of the leakage based linear precoding for multi-user MIMO is categorized into two criterions. First, maximizing the SLNR (signal to leakage plus noise ratio), the signal power compared to the sum of the interference that transmitter induces to another user (leakage). The second is minimizing the leakage plus noise.

The block diagonalization perfectly cancels the multi-user interference by placing the unintended users at the null space of the intended user channel. In block diagonalization, the weight must fulfill $H_j w_k = 0, j \neq k$ [10]. The new channel state matrix $\tilde{h}_k = [h_1\, h_2 \cdots h_{k-1} h_{k+1} \cdots h_K]^T$ where $[.]^T$ is a matrix transpose. The new single value decomposition (SVD) of $\tilde{h}_k$ is formulated by $\tilde{h}_k = \tilde{U}_k\, \tilde{\Sigma}_k [\tilde{V}_k^{(1)}\, \tilde{V}_k^{(0)}]^H$ with $[.]^H$ of the hermitian matrix transpose. $\tilde{V}_k^{(0)}$ indicates the null space, $\tilde{V}_k^{(1)}$ represents the single space except for user k. We can fulfill the requirement $H_j w_k = 0, j \neq k$ by using the weight matrix $\tilde{V}_k^{(0)}$ in $h_k\tilde{V}_k^{(0)} = 0$. Block diagonalization MU MIMO is equal to K parallel SU MIMO. Consequently, the SVD multi-user MIMO is achieved by the SVD operation of the SVD single user, $\bar{h}_k = \bar{U}_k\, \bar{\Sigma}_k [\bar{V}_k^{(1)}\, \bar{V}_k^{(0)}]^H$ with $\bar{\Sigma}_k$ is the diagonal matrix of the null space eigenvalues. Therefore, the SVD weight matrix at the transmitter is defined as $W_{Tx} = \bar{V}_k^0 \bar{V}_k^1$ while at receiver the weight is given as $W_{Rx} = \bar{U}_k^H$.

Multiply $\tilde{h}_k$ by W_{Tx} converts multi-user MIMO channel to multiple single-user MIMO channel. It is block diagonalization which is defined as [13]

$$\tilde{h}_k W_{Tx} = \begin{bmatrix} h_1 W_{T1} & 0 & & \cdots & \cdots & 0 \\ 0 & h_2 W_{T2} & & \cdots & \cdots & 0 \\ \vdots & \vdots & & \ddots & \cdots & 0 \\ \vdots & \vdots & \vdots & h_{k-1} W_{Tk-1} & & 0 \\ 0 & 0 & 0 & 0 & & h_k W_{Tk} \end{bmatrix} \tag{6}$$

The MMSE (minimum mean squared error) precoding clearly tried to minimize the inter-user interference and inter-stream interference [12].

$$\min_{P_k} E[\|h_k w_k s_k - I_M\|^2] + +E\left[\sum_{j=1,j\neq k}^{K}\|h_k w_j s_j\|^2\right] + E\|n_k\|^2 \tag{7}$$

At the receiver, the decoded received signal is given as follows:

$$r_k = g_k h_k w_k s_k + g_k \sum_{j=1,j\neq k}^{K} h_k w_j s_j + g_k n_k \tag{8}$$

$$\begin{aligned} \mathrm{MSE_k} &= E(\|r_k - x_k\|) \\ &= \mathrm{tr}\Big((g_k h_k w_k - I)(g_k h_k w_k - I)^H \\ &\quad + \sum_{j=1,j\neq k}^{K} g_k\, h_k w_j (g_k h_k w_j)^H \\ &\quad + n_k g_k g_k{}^H\Big) \end{aligned} \tag{9}$$

The optimization problem can be written

$$\min_{g_1 \cdots g_k} \sum_{k=1}^{K} \mathrm{tr}\Big((g_k h_k w_k - I)(g_k h_k w_k - I)^H + \sum_{j=1, j\neq k}^{K} g_k h_k w_j (g_k h_k w_j)^H + n_k g_k g_k{}^H \Big) \quad (10)$$

The interference plus noise $z_j = \sum_{j=1, j\neq k}^{K} s_j h_k w_j + n_k$ with $E\{S_j S_j^H\} = I$ so $E\{z_j z_j^H\} = \sum_{j=1,j\neq k}^{K} (h_k w_j)^H (h_k w_j) + \sigma_k^2 I$ and $\left(\sum_{j=1,j\neq k}^{K} (h_k w_j)^H (h_k w_j) + \sigma_k^2 I\right)^{-1} = A_k^H A_k$. Utilizing the decoder can be written $g_k = \frac{w_k^H h_k^H A_k^H}{\|w_k^H h_k^H A_k^H\|_F} A_k$. The precoding matrix user k, w_k, is formulated as follows :$w_k = V_k C_k \Lambda_k$ with V_k placed in null space of $\tilde{h}_k$, $C_k^{optm} = \arg\max_{C_k} \frac{\mathrm{tr}(C_k^H (V_k C_k A_k)^H V_k C_k A_k h_k)}{\mathrm{tr}(C_k^H (M_k \sigma_0^2 + \bar{h}_k^H \bar{h}_k) C_k)}$, and $\Lambda_k^{optm} = \min_{\Lambda_k} \left(\left(\Lambda_k^H \frac{C_k^H V_k^H h_k^H A_k^H}{\|A_k h_k w_k\|_F} A_k h_k V_k C_k \Lambda_k \right)^2 - 2\Lambda_k^H \frac{C_k^H V_k^H h_k^H A_k^H}{\|A_k h_k w_k\|_F} A_k h_k V_k C_k \Lambda_k \right)$. I_M denotes an MxM identity matrix. $\|\cdot\|_F, (\cdot)^{-1}, \mathrm{tr}(\cdot), E(\cdot), (\cdot)^H$ stand for Frobenius norm, inverse, trace, expectation, conjugate transpose.

Based on some previous formulas, the outage probability based on the interference and noise can be derived as follows:

the transmit power per user can be defined [14] :

$$P_U \triangleq P_t / K \quad (11)$$

from (2), the SINR of user k^{th} can be expressed

$$P_U \triangleq P_t / K \; SINR_k = P_u M \cdot X_k^2 / (1 + P_u Y_k) \quad (12)$$

next, we focused on the variances of $1 + P_u Y_k$ and X_k^2, respectively. The variance of the desired signal power is formulated as follows :

$$\mathrm{Var}\,(X_k^2) = 4/M + \mathcal{O}(1/M^2) \quad (13)$$

with using the received signal :

$$\mathrm{Var}\,(Y_k) = K - 1 + (K-1)(K-2)/M \quad (14)$$

we can get the variance of $1 + P_u Y_k$:

$$\mathrm{Var}\,(1 + P_U Y_k) = P_u^2 \left[K - 1 + \frac{(K-1)(K-2)}{M} \right] > \frac{P_t^2 (K-1)}{K^2} \quad (15)$$

Based on (2) and (12), the interference power is strongly influenced by P_t and K. It is significantly larger than the variance of signal power when $P_t^2 M \gg K$. However, when the number of antennas in the transmitter (M) approach to infinity ($M \to \infty$), it is the variance of the signal power (X_k^2) that decreases to 0. Thus, the desired signal power becomes deterministic.

With γ_{th} as the SINR threshold, the outage probability of user k can be formulated as follows:

$$P_{out} = \mathbb{P}\left(P_u M \frac{X_k^2}{1 + P_u Y_k} < \gamma_{th} \right) \approx \mathbb{P}\left(P_u M \frac{1 + \frac{1}{M}}{1 + P_u Y_k} < \gamma_{th} \right) \quad (16)$$

$$P_{out} = \begin{cases} 1, & \gamma_{th} \geq MP_u \\ \mathbb{P}\left(Y_k > \frac{M+1}{\gamma_{th}} - \frac{1}{P_u} \right), & \text{otherwise} \end{cases} \quad (17)$$

III. Results and Analysis

We provide simulation results of leakage based linear precoding scheme particularly BD SLNR and MMSE SLNR. In the simulation, it was assumed that the transmitter knows perfectly of the channel state (CSIT) and the MIMO channels are independent and identically distributed (iid) with zero mean unit variance. These precoding schemes are using equal power allocation.

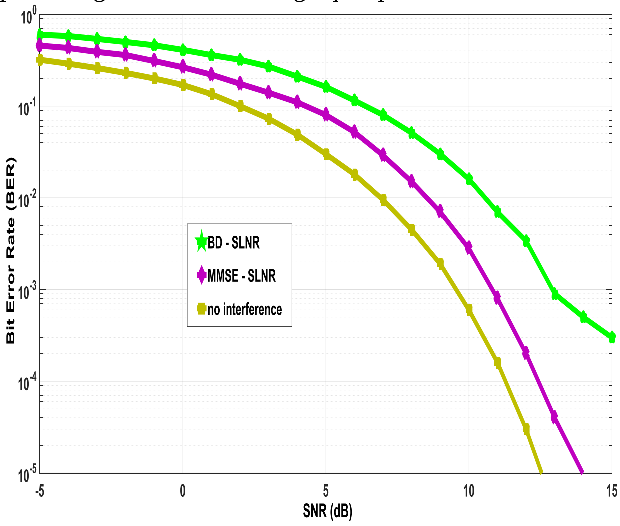

Fig. 6. BER performance compare BD and MMSE SLNR precoding with CSIT

Fig. 6 shows that the MMSE SLNR precoding scheme produces better BER than the BD SLNR precoding scheme. For specific target BER 10-3, the MMSE SLNR needs a 10.8 dB while BD SLNR requires a 13.4 dB of SNR. There is about 3.4 dB of precoding gain. The MMSE SLNR matrix can arrange the dynamic power allocation and reduce the inter-user interference (IUI) in the conventional downlink MU-MIMO system.

From Fig. 7, we can see that the results of MMSE SLNR and BD SLNR are almost similar, only a little bit different. However, the BD precoding scheme gives the worst result than the leakage based precoding scheme. At specific 15 dB of SNR, the BD precoding yields about 7 bps/Hz while the leakage based precoding scheme generates about 11 bps/Hz. At the low SNR regime (< 10 dB), the BD precoding scheme slightly outperforms than the leakage based precoding scheme. The sum-rate capacity of leakage based precoding scheme will lead to a medium-high SNR regime (> 10 dB). The reason for this that the MMSE SLNR can reduce the inter-stream interference (ISI) and inter-user interference (IUI).

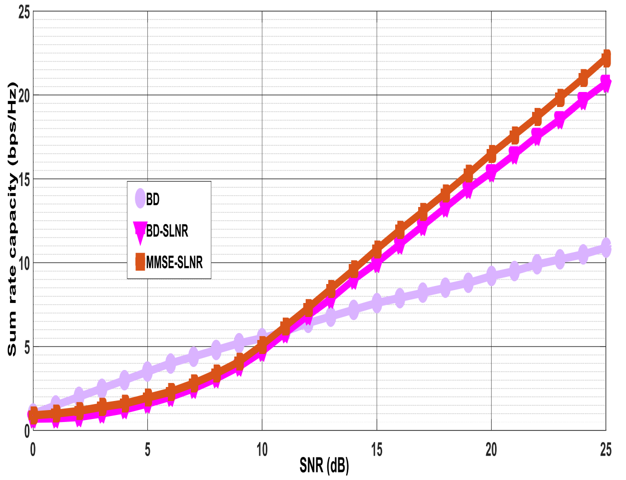

Fig. 7. Sum-rate comparison of MMSE SLNR and BD SLNR for (2,2) x 4 MU MIMO downlink

Fig. 8 shows the SINR outage curves with antenna configuration (N,M,K) = (4,2,2) and receive SNR = – 7 dB. Based on Fig. 8, the results show that the MMSE SLNR outperforms the BD SLNR excepts in low SNR regime. The figure describes the presence of interference, the MMSE SLNR can reduce the outage better than the BD SLNR. For specific 2 dB SINR, the probability of an outage is 0.65 for MMSE SLNR and 0.86 for BD SLNR.

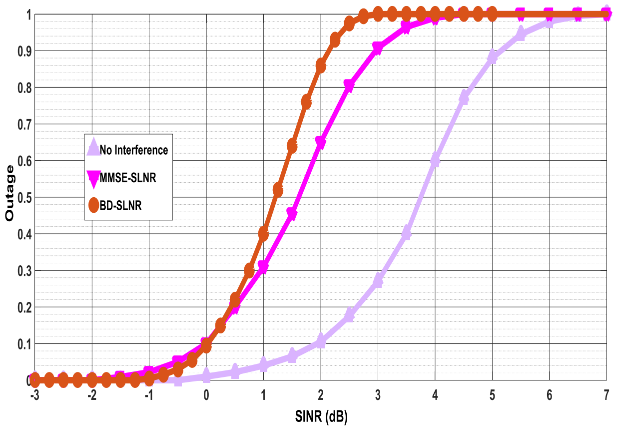

Fig. 8. Outage curve for SINR (N,M,K) = (4,2,2) with receive SNR = -7 dB

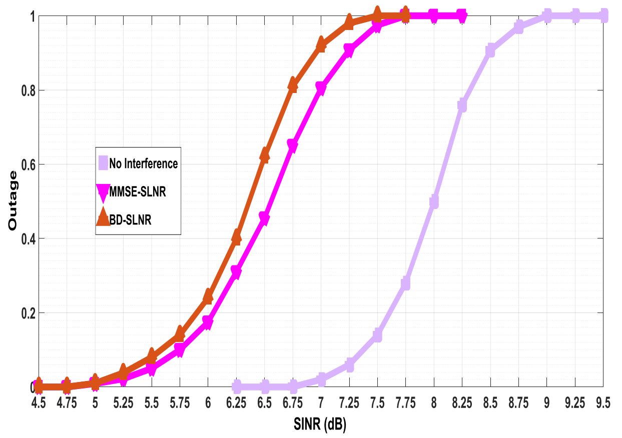

Fig. 9. Outage curve for SINR (N,M,K) = (4,2,2) with receive SNR = 6 dB

The result in Fig. 9 generally shows a similar trend with Fig. 8, increasing the SINR value as increasing the received SNR (6 dB).

Fig. 10 depicts the performance of the outage probability. We set the SINR threshold (γ_{th}) = 8 dB, the number of users is four, and transmit power is 8 dB. Based on Fig. 10, increasing the number of antennas at the transmitter (M) significantly influence the outage probability performance. Increasing the number of antennas improve the quality of the links which is orthogonal each other. Retaining of the link quality will keep the level of outage probability.

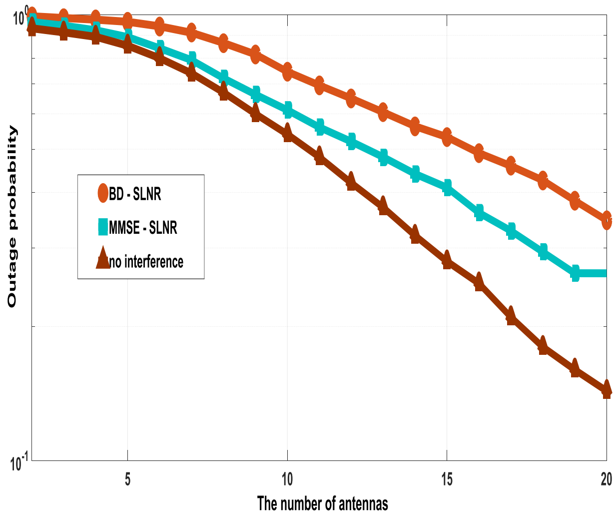

Fig. 10. Outage probability as a function of the number of antennas (M), K=4, Pt= 8 dB, γ_{th} = 8 dB

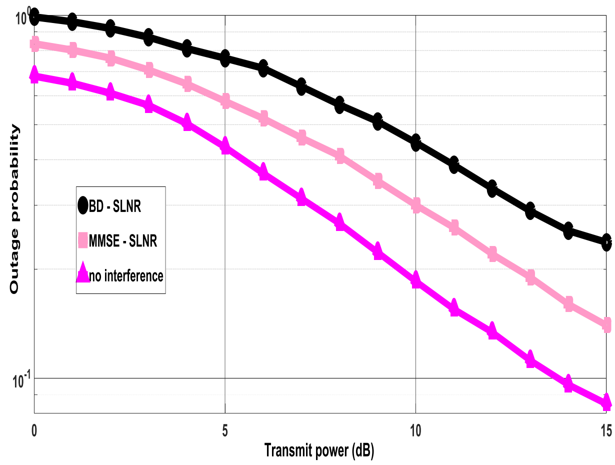

Fig. 11. Outage probability versus transmit power (Pt), K=4, γ_{th} = 8 dB, M = 6

In addition, Fig. 11 describes the impact of enlarging of the transmit power in the outage probability system. In this section, we set the SINR threshold (γ_{th}) = 8 dB, the number of users is four, and the number of antennas is eight. Enlarging the transmit power makes the signal more robust to propagation attenuation along with traveling, thereby it will increase the level of a received signal and reduce the level of outage probability. Based on Fig. 11, MMSE SLNR outperforms than BD SLNR, at specific transmit power 10 dB MMSE SLNR generates about 0.3 of outage probability and BD SLNR only creates about 0.65 of outage probability.

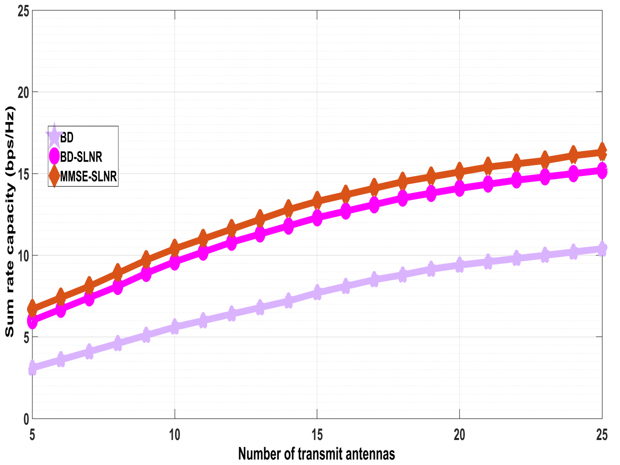

Fig. 12. Sum-rate performance versus the number of transmit antennas with specific SNR 15 dB

Fig. 12 illustrates the sum rate capacity as a function of the number of transmit antennas. As observed from the figure, we can see that there is a significant gap between BD and leakage based precoding scheme (MMSE SLNR and BD SLNR). For specific 15 transmit antennas, the leakage based precoding scheme obtains about 12 bps/Hz while the BD precoding scheme only gets 7 bps/Hz. In addition, the performance of leakage based precoding scheme significantly outperforms than the BD precoding scheme. The sum rate of leakage based precoding scheme increases as the number of transmit antennas grow large.

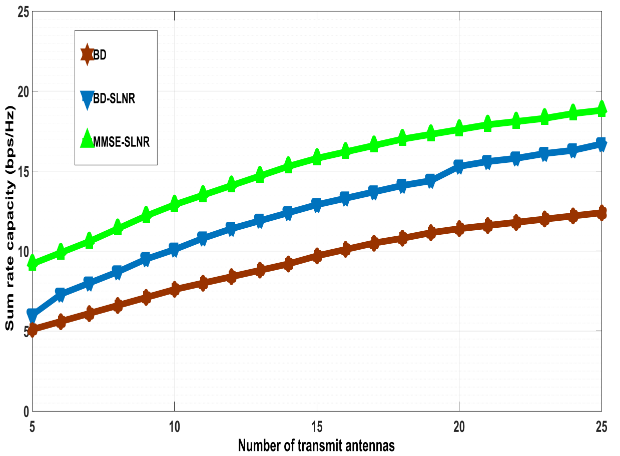

Fig. 13. Sum-rate performance versus the number of transmit antennas with specific SNR 20 dB

Fig. 13 also illustrates the sum rate capacity as a function of the number of transmit antennas with higher SNR value, i.e. 20 dB. Higher SNR value indicates better link quality, thus the system can transfer with the high data rate. Comparing from the Fig. 13 and Fig. 12, at specific 15 transmit antennas that the MMSE SLNR with SNR 20 dB reaches about 16 bps/Hz while the MMSE SLNR with SNR 15 dB only keeps 13 bps/Hz. Furthermore, to achieve the same level of sum rate that the system with SNR 15 dB requires more number of transmit antennas. We can see in Fig. 12 that to reach about 10 bps/Hz of sum rate the MMSE SLNR with SNR 15 dB needs 9 transmit antennas while the MMSE SLNR with SNR 20 dB requires about 6 transmit antennas.

IV. Conclusions

In this work, we provide the performance of leakage based precoding scheme, i.e., MMSE-SLNR and BD SLNR. The leakage based precoding scheme yields a better bit error rate, higher sum rate capacity and lower outage than non-leakage based (BD). Moreover, the leakage based precoding scheme generates better performance as increases the number of transmit antennas. Generally, the MMSE SLNR gives better performance than BS SLNR. The reason for this condition that the MMSE SLNR can reduce the IUI and ISI. The leakage based precoding scheme improves the performance of downlink multiuser MIMO.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Subuh Pramono was the principal investigator for this project; Eddy Triyono contributed in the design of the model system; Budi Basuki simulated and analyzed the obtained data; All authors had approved the final version.

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