Studying the Performance of Linear Precoding Algorithms based on Millimeter-wave MIMO Communication System

Rania H. El-abd, Haythem H. Abdullah, Mohamed abd el-azim, Ahmed sh. Samrah, Ahmed abo talb

Abstract— the main difficulty in multi-input multi-output (MIMO) channels is the separation of the data streams which have been sent in parallel. Precoding is a technique which exploits transmission diversity by properly weighing the data stream. This technique will reduce the Perversion effects of the communication channel. In this paper, we have altogether assessed the impact of various linear precoding (LP) algorithms on Millimeter wave MU-MIMO wireless communication system with and without channel state information. We have proposed to think about the impact of increasing number of base-station (BS) antenna on the bit error rate (BER) and achievable sum-rate performance of the different LP algorithms. The simulation results had been shown that as the number of user's increases, BER value of Maximum ratio transmission (MRT) is better than Zero-forcing (ZF) in SNR range from 0 to15 dB but ZF gives the better value of BER at SNR ≥ 15 than MRT however, it has not changed by increasing number of users. While BER of Regularized Zero-forcing (RZF) and Minimum mean square error (MMSE) is improved with increasing number of users. MMSE gives the lowest BER in the across SNR range. Therefore, the MMSE algorithm is the best of them. As for the achievable sum rate, the achievable rates of MMSE, ZF, RZF, and MRT are increased by increasing the number of antennas.

Index Terms— MIMO, linear precoding (LP), algorithms, base-station (BS), bit error rate (BER), achievable sum rate.

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1 INTRODUCTION

Large MIMO innovation has got much attraction recently as it promises actually broadband wireless networks [1] since it is key to meet with the demand of exponentially increasing data traffic [2]. Large MIMO systems use BS antenna arrays, with a lot of elements, simultaneously serving numerous terminals (users) utilizing a similar time and frequency resources.

Generally, MU-MIMO systems not only suffering from the noise and the inner-antenna interfering but have been also affected by multi-user interference (MUI) through downlink transmission, which means of channel-aware precoding strategies have been executed at the BS. Precoding techniques for MIMO transmissions have lately gained increasing interest with the overview of MU-MIMO, in which a big number of transmit antennas are utilized at the BS to concurrently serve different receivers [3].

Widely-linear methodologies have long been used for signal processing in MIMO frameworks [4], [5].

Channel inversion-based linear precoding algorithms such as zero-forcing channel inversion can still be used to cancel the MUI with the lower complexity [6], [7].

In the course of the most recent couple of years, numerous works have examined the zero-forcing beamforming for single-stream transmission per user and the zero-forcing precoding for many streams per user as the generalized one antenna [8], [9].

In [10] authors focuses on the design of MRT precoding for MU-MIMO downlink transmission. Block diagonalization (BD) precoding illustrates on MU-MIMO systems have the high complexity, because the transmitter precoding matrices created by singular value decomposition (SVD) are successively calculated twice. Simulations obtain that the suggested algorithm has numerous gains over the conventional BD precoding in various MU-MIMO systems.

In [11] authors are obtained weighted minimum mean squared error (WMMSE) for multiuser downlink transmissions. The simulation demonstrates a huge enhancement in the achievable sum-rate by the suggested robust WMMSE precoder, compared to non-robust linear precoder designs.

In this article, we have contemplated the Performance of Linear Precoding Algorithms based on Millimeter-wave MIMO Communication System.

The rest of the article is prepared as follows:

The system model is illustrated in the second section. The third section presents the linear precoding algorithms. The fourth section mainly introduces the achievable sum rate of linear precoding algorithms. The Flowchart of linear precoding algorithms is illustrated in the fifth section. The sixth section is the numerical result. Finally, a conclusion of this article is presented in the last section.

The symbol utilized in this article $(\bullet)^{T}$, $(\bullet)^{*}$, $(\bullet)^{H}$ note the transpose, conjugate, and conjugate transpose, respectively.

2 SYSTEM MODEL

Uncoded MU-MIMO downlink channel is considered, with N_b transmit antennas at the BS and N_k receive antennas at the kth user equipment (UE). With K users in the system, the whole number of receive antennas is $N_u = \sum_{k=1}^{K} N_k$. A block diagram of such a system has appeared in Figure 1.

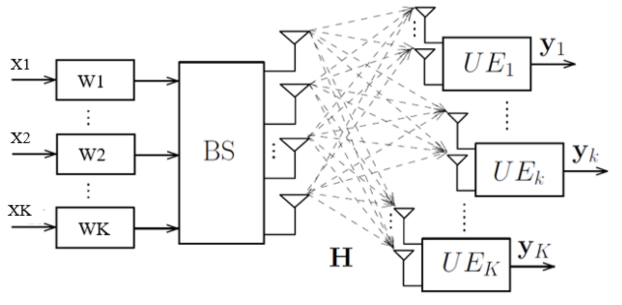


Fig. 1 MU-MIMO Channel Model

From the system model, the consolidated channel matrix H and the precoding matrix W are given by

$$H = [H_1^T \quad H_2^T \quad \cdots \quad H_K^T]^T \in \mathbb{C}^{N_u \mathrm{x} N_b} \qquad (1)$$

$$W = [W_1 \quad W_2 \quad \cdots \quad W_K] \in \mathbb{C}^{N_u \mathrm{x} N_b} \qquad (2)$$

Where $H_k \in \mathbb{C}^{N_k \mathrm{x} N_b}$ is the ith user's channel matrix. The quantity $W_K \in \mathbb{C}^{N_b \mathrm{x} N_k}$ is the kth user's precoding matrix. For a flat fading MIMO channel, the received signal $y_k \in \mathbb{C}^{N_k \mathrm{x} 1}$ at the kth user is given by

$$y_k = H_k W_k x_k + H_k \sum_{j=1, j \neq k}^{K} W_j x_j + n_k \qquad (3)$$

Where the quantity $x_k \in \mathbb{C}^{N_k \mathrm{x} 1}$ is the kth user's transmitted signal, and $n_k \in \mathbb{C}^{N_k \mathrm{x} 1}$ is the kth user's Gaussian noise with independent and identically distributed (i.i.d.) entries of zero mean and variance σ_n^2.

3 MU-MIMO LINEAR PRECODING

Figure 1 is simplified in figure 2. For LP, the precoding operator $p\{.\}$ in Figure 2 is a matrix $W \in \mathbb{C}^{N_b \mathrm{x} N_k}$ Depending on the application, this matrix can have different purposes, such as maximizing the SINR related to the signals received by the terminals. The most common linear precoding methods are the MRT, ZF, RZF, and MMSE.

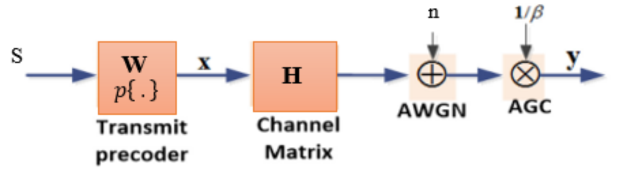


Fig. 2 linear precoding schemes

3.1 ZERO-FORCING PRECODING

In this technique, only one user can activate at a time and all other users nullify at that time.

Zero-forcing precoding is more computationally expensive for it performs a $N_k \mathrm{x} N_b$ matrix inversion. The precoded signal by ZF is the solution of the following convex optimization problem

$$\underset{x \in \mathbb{C}^{N_b \mathrm{x} 1}}{\text{minimize}} \|Hx - s\|_2^2 \qquad (4)$$

The problem (4.1) is known as the least-squares problem and has infinitely many solutions due to the fact that H is a full-row rank matrix with much more columns than rows. A common choice among these infinity solutions is the minimum l_2-norm solution, which yields the ZF-precoded signal

$$X_{ZF} = H^H (HH^H)^{-1} s \qquad (5)$$

Where the ZF precoding matrix is

$$W_{ZF} = H^H (HH^H)^{-1} = (H)^{\dagger} \qquad (6)$$

Which is the Moore-Penrose pseudo-inverse matrix. Note that ZF precoding inverts perfectly the channel no matter the number of base station antennas N_b. This fact is a significant advantage for ZF precoding because it can guarantee reasonable channel capacity and bit-error rate.

3.2 REGULARIZED ZERO-FORCING PRECODING

Regularized zero-forcing precoding is very similar to ZF, except the diagonal loading factor added prior to the inversion of the matrix HH^H. The RZF precoding is also the solution of a convex optimization problem, but now there is a constraint on the power of the precoded signal, i.e., now there is an l_2-norm regularization in the problem. The l_2-norm regularization is known as Ridge/Tikunov regression [2].

The formulation of RZF precoding can be written as

$$\underset{x \in \mathbb{C}^{M \mathrm{x} 1}}{\text{minimize}} \|H^T x - s\|_2^2 \qquad (7)$$

$$\text{Subject to } \|x\|_2^2 = \xi$$

Where $\xi \in \mathbb{R}_+$ is the power of x. The solution of (4) is given by

$$X_{RZF} = H^H (HH^H + \xi I_K)^{-1} s \qquad (8)$$

And the RZF precoding matrix is given by

$$W_{RZF} = H^H (HH^H + \xi I_K)^{-1} \qquad (9)$$

The RZF precoding performance is bounded by ZF precoding performances. When $\xi \rightarrow 0$, RZF precoding approaches to ZF precoding. Thus, RZF precoding can be a flexible alternative to ZF precoders.

3.3 MINIMUM MEAN SQUARE ERROR PRECODING

The MMSE precoding is a specific case of RZF precoding. This regularization factor in MMSE precoding takes into consideration the effect of the environment noise, unlike other precoding algorithms described in this section.

MMSE precoding is the optimal linear precoding in MU-MIMO downlink system. This technique is generated by the mean square error (MSE) method. Owing to average power at each transmitted antenna is constrained, the Lagrangian optimization method is used for obtaining this precoder.

Firstly, we start to consider the MSE of the signal. The MSE can be written as [12]

$$\epsilon = \mathbb{E}\,[\|\beta y - x\|^2] \qquad (10)$$

Where β is a scalar of Wiener filter.

Firstly, we find W and β to minimize the MSE under the power constraint. Then,

$$[\widehat{W}, \hat{\beta}] = \arg \min_{A,\beta} \epsilon \tag{11}$$

$$S.t. \mathbb{E}\,[\|s\|^2] = P_{tr}$$

To solve the optimization problem, the Lagrangian method is used for this problem. Then,

$$\mathcal{L}(W, \beta, \lambda) = \mathbb{E}\,[\|\beta y - x\|^2] - \lambda tr(s^H s - P_{tr}) \tag{12}$$

Where $\lambda \in \mathbb{R}$ is the Lagrangian factor. In order to find W, β, and λ to minimize the MSE, we take derivatives with respect to $W\ and \lambda$. As a result, AMMSE can be expressed as

$$W = \frac{1}{\beta} H^H (HH^H + \frac{K}{P_{tr}} \sigma^2 I_K)^{-1} \tag{13}$$

Where σ^2 is noise variance

$$\beta = \sqrt{\frac{tr(W_{MMSE} {W_{MMSE}}^H)}{P_{tr}}} \tag{14}$$

Where

$$W_{MMSE} = H^H (HH^H + \frac{K}{P_{tr}} \sigma^2 I_K)^{-1} \tag{15}$$

3.4 MAXIMUM RATIO TRANSMISSION PRECODING

MRT is one of the common techniques of linear precoding which maximizes the SNR. MRT works well in the MU-MIMO system where the base station radiates low signal power to the users. MRT approaches MMSE when $Ptr \rightarrow 0$. Hence, from (4.10), W_{MRT} can be expressed as

$$W = \frac{1}{\beta} H^H \tag{16}$$

$$\beta = \sqrt{\frac{tr(W_{MRT} {W_{MRT}}^H)}{P_{tr}}} \tag{17}$$

$$W_{MRT} = H^H \tag{18}$$

4 THE ACHIEVABLE SUM RATE

The system performance can be defined by several methods. One method, to quantify the system performance, is the achievable rate. The achievable rate is followed by Shannon theorem. This theory tells the maximum rate, which the transmitter can transmit over the channel. This section will describe the achievable rate and assumes that the channel is ergodic and that all parameters are Gaussian random processes.

From (3), let y_K and x_K be the k^{th} elements of the $K \times 1$ vector y and x respectively. Then, the y_K can be expressed as

$$y_K = h_k^T w_k x_k + \sum_{i=1, i \neq K}^{K} h_k^T w_i x_i + n_k \tag{19}$$

The energy of the desired signal is given by

$$\mathbb{E}[|h_k^T w_k x_k|^2] = |h_k^T w_k|^2 \mathbb{E}[|x_k|^2] = |h_k^T a_k|^2 \tag{20}$$

The inter-user interference plus noise energy is given by

$$\mathbb{E}\left[\left|\sum_{i=1,i\neq K}^{K} h_k^T w_i x_i + n_k\right|^2\right] = \sum_{i=1,i\neq K}^{K} |h_k w_i|^2 \ \mathbb{E}[|x_i|^2] + \mathbb{E}[|n_k|^2] = \sum_{i=1,i\neq K}^{K} |h_k w_i|^2 + 1 \tag{21}$$

From Shannon theorem, the channel capacity over Additive White Gaussian Noise channel is derived by [5]

$$R = log_2(1 + SNR) \ \ \text{(bits/s/Hz)} \tag{22}$$

With MU-MIMO downlink system, the transmitter must know channel state information. CSI is a key of multiuser communication. Typically, the transmitter transmits multiple data streams to each user simultaneously and selectively with CSI [6]. All receivers send channel estimation feedback to the transmitter on the reverse link, so the transmitter obtains CSI. Hence, the transmitter communicates all receivers with perfect CSI. With an MU-MIMO system, the interference consists of additive noise and interference between the users themselves. Then, the achievable rate of $the\ kth$ user for MU-MIMO downlink system can be expressed as

$$R_k = \mathbb{E}[log_2(1 + SINR_k)\,] \ \text{(bits/s/Hz)} \tag{23}$$

From (4.17) and (4.18), (4.20) can be written as

$$SINR = \frac{\text{The desired signal energy}}{\text{inter} - \text{user interference plus noise energy}} \tag{24}$$

$$= \frac{|h_k^T w_k|^2}{1 + \sum_{i=1,i\neq K}^{K} |h_k w_i|^2}$$

$$R_k = \mathbb{E}\left[log_2\left(1 + \frac{|h_k^T w_k|^2}{1 + \sum_{i=1,i\neq K}^{K} |h_k w_i|^2}\right)\right] \tag{25}$$

4.1 THE ACHIEVABLE RATE WITH ZF PRECODING

From (6), we obtain the received vector with ZF as

$$y = \frac{1}{\beta} H[H^H (HH^H)^{-1}]x + n \tag{26}$$

Where

$$\beta = \sqrt{\frac{tr(HH^H (HH^H)^{-2})}{P_{tr}}} \tag{27}$$

Let y_K, x_K, and n_K be the k^{th}elements of $K \times 1$ vectors $y, x, and\ n$ respectively and we define the k^{th} column of W_{ZF} as

$$w_k = H^H g_k \tag{28}$$

Where g_k is the k^{th} column of $(HH^H)^{-1}$. From (28), the received vector of $the\ k^{th}$ user with ZF is given by

$$y_K = \frac{1}{\beta} h_k^T H^H g_k\, x_k + \frac{1}{\beta} \sum_{i=1,i\neq K}^{K} h_k H^H g_i\, x_i + n_k \tag{29}$$

The achievable rate of $the\ k^{th}$ user with ZF is given by

$$R_k^{ZF} = \mathbb{E}\left[log_2\left(1 + \frac{\frac{1}{\beta^2}\left|h_k^T H^H g_k\right|^2}{1 + \frac{1}{\beta^2} \sum_{i=1,i\neq K}^{K} \left|h_k^T H^H g_i\right|^2}\right)\right] \tag{30}$$

4.2 THE ACHIEVABLE RATE WITH RZF PRECODING

From (8), we obtain the received vector with RZF as

$$y = \frac{1}{\beta} H[H^H(HH^H + \xi I_K)^{-1}]x + n \tag{31}$$

Where

$$\beta = \sqrt{\frac{tr(HH^H(HH^H + \xi I_K)^{-2})}{P_{tr}}} \tag{32}$$

Let y_K, x_K, and n_K be the k^{th} elements of $K \times 1$ vectors $y, x, and\ n$ respectively and we define the k^{th} column of W_{RZF} as

$$w_k = H^H o_k \tag{33}$$

Where o_k is the k^{th} column of $(HH^H + \xi I_K)^{-1}$. From (33), the received vector of $the\ k^{th}$ user with RZF is given by

$$y_K = \frac{1}{\beta} h_k^T H^H o_k x_k + \frac{1}{\beta} \sum_{i=1, i \neq K}^{K} h_k^T H^H o_i x_i + n_k \tag{34}$$

The achievable rate of $the\ k^{th}$ user with RZF is given by

$$R_k^{RZF} = \mathbb{E}\left[log_2\left(1 + \frac{\frac{1}{\beta^2}\left|h_k H^H o_k\right|^2}{1 + \frac{1}{\beta^2}\sum_{i=1, i \neq K}^{K}\left|h_k^T H^H o_i\right|^2}\right)\right] \tag{35}$$

4.3 THE ACHIEVABLE RATE WITH MMSE PRECODING

From (13), we obtain the received vector with MMSE as

$$y = \frac{1}{\beta} H\left[H^H\left(HH^H + \frac{K}{P_{tr}}\sigma^2 I_K\right)^{-1}\right]x + n \tag{36}$$

Where

$$\beta = \sqrt{\frac{tr\left(HH^H\left(HH^H + \frac{K}{P_{tr}}\sigma^2 I_K\right)^{-2}\right)}{P_{tr}}} \tag{37}$$

Let y_K, x_K, and n_K be the k^{th} elements of $K \times 1$ vectors $y, x, and\ n$ respectively and we define the k^{th} column of W_{MMSE} as

$$w_k = H^H \Lambda_k \tag{38}$$

Where Λ_k is the k^{th} column of $\left(HH^H + \frac{K}{P_{tr}}\sigma^2 I_K\right)^{-1}$. From (33), the received vector of $the\ k^{th}$ user with MMSE is given by

$$y_K = \frac{1}{\beta} h_k^T H^H \Lambda_k x_k + \frac{1}{\beta} \sum_{i=1, i \neq K}^{K} h_k^T H^H \Lambda_i x_i + n_k \tag{39}$$

The achievable rate of $the\ k^{th}$ user with MMSE is given by

$$R_k^{MMSE} = \mathbb{E}\left[log_2\left(1 + \frac{\frac{1}{\beta^2}\left|h_k H^H \Lambda_k\right|^2}{1 + \frac{1}{\beta^2}\sum_{i=1, i \neq K}^{K}\left|h_k^T H^H \Lambda_i\right|^2}\right)\right] \tag{40}$$

4.4 THE ACHIEVABLE RATE WITH MRT PRECODING

From (16), we obtain the received vector with MRT as

$$y = \frac{1}{\beta} HH^H x + n \tag{41}$$

Where

$$\beta = \sqrt{\frac{tr(HH^H)}{P_{tr}}} \tag{42}$$

Let y_K, x_K, and n_K be the k^{th} elements of $K \times 1$ vectors $y, x, and\ n$ respectively and we define the k^{th} column of W_{MRT} as

$$w_k = h_k^* \tag{43}$$

From (4.40), the received vector of $the\ k^{th}$ user with MRT is given by

$$y_K = \frac{1}{\beta} h_k^T h_k^* x_k + \frac{1}{\beta} \sum_{i=1, i \neq K}^{K} h_k^T h_i^* x_i + n_k \tag{44}$$

The achievable rate of the k^{th} user with MRT is given by

$$R_k^{MRT} = \mathbb{E}\left[log_2\left(1 + \frac{\frac{1}{\beta^2}\|h_k\|^4}{1 + \frac{1}{\beta^2}\sum_{i=1, i \neq K}^{K}|h_k^T h_i^*|^2}\right)\right] \tag{45}$$

5 FLOWCHART OF LINEAR PRECODING ALGORITHMS

Figure (3) show that the flowchart of linear precoding algorithms to calculate BER of MRT, ZF, RZF and MMSE precoding algorithm versus SNR range in case of changing the number of antennas and number of users to show Who is the best algorithm.

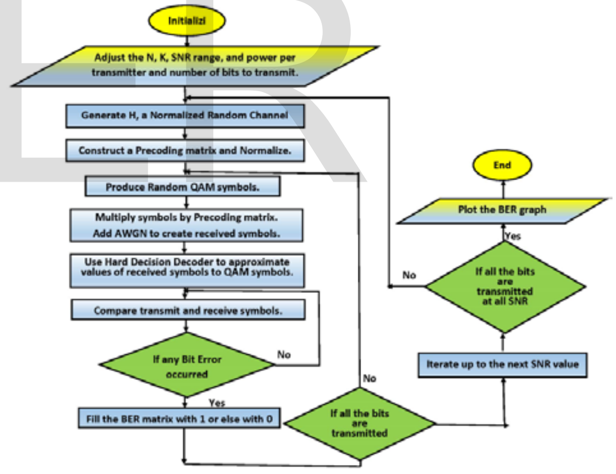


Fig. 3 flowchart of linear precoding algorithms

6 SIMULATION RESULT

Precoding is an important technique to explore the significant performance in terms of bit-error rate (BER) as well as the achievable sum-rates for MU-MIMO downlink transmission. In computer MATLAB R2014b simulations, considered two scenarios N=20, K=10 and N=60, K=10. The quadrature amplitude modulation (QAM) scheme along Rayleigh fading channel environment with 100 frames and 10,000 iterations of Monte Carlo channel realizations in the computer simulations are used.

The MU-MIMO system performance is measured by the BER and achievable rate. The achievable rate of the user 1 is analyzed because all of the users have the same achievable rate properties. Then, the achievable rate only for the user 1 is measured by measure the achievable rate of user 1 within 10,000 channel realization. After these achievable rates are obtained, average them. The average value is used to study the performance of MU-MIMO downlink system.

Figure 4 depicts the BER performance of MU-MIMO system using linear precoding algorithms MRT, ZF, RZF, and MMSE across the entire SNR range. This system consists of the number of antennas N=20 and the number of users K=10 .

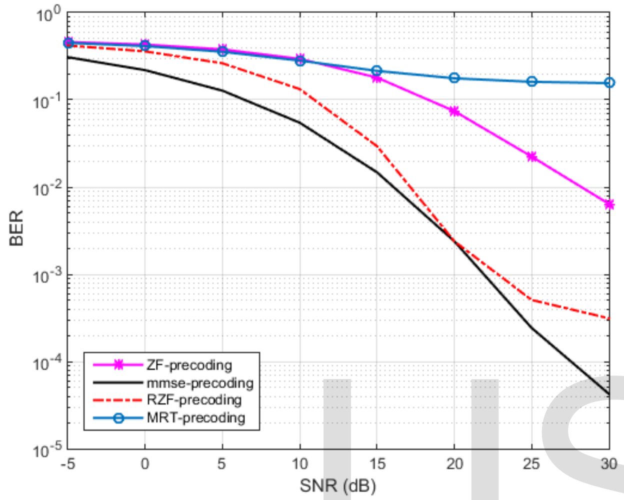


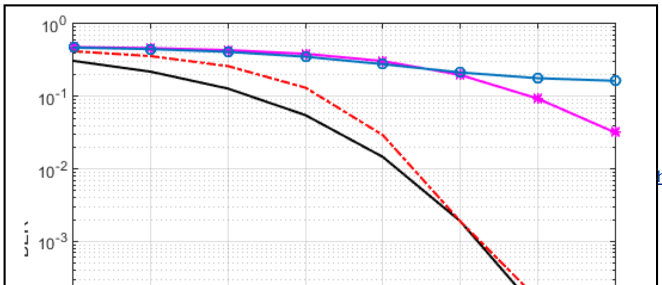
Fig. 4 an illustration of the BER of an MU-MIMO system N=20, K=10 (with various linear precoding methods)

Results show that MRT gives the high value of BER at high SNR range. While ZF gives the better value of BER at high SNR than MRT. On the other sides, RZF performs the low BER compared with ZF at high SNR. But, MMSE gives the lowest BER in the across SNR range. Therefore, the MMSE algorithm is the best of them.

Figure 5 depicts the BER performance of MU-MIMO system using linear precoding algorithms MRT, ZF, RZF, and MMSE across the entire SNR range. This system consists of the number of antennas N=60 and the number of users K=10, in order to know what the effect of increasing the number of users.

Results show that MRT still gives the greatest value of BER at high SNR range. As the number of users increases BER value of MRT is enhanced than ZF in SNR range from 0 to15 dB but ZF gives the better value of BER at SNR ≥ 15 than MRT however, it has not changed by increasing number of users.

While BER of RZF and MMSE are improved with increasing number of users. MMSE gives the lowest BER in the across SNR range. Therefore, the MMSE algorithm is the best of them.



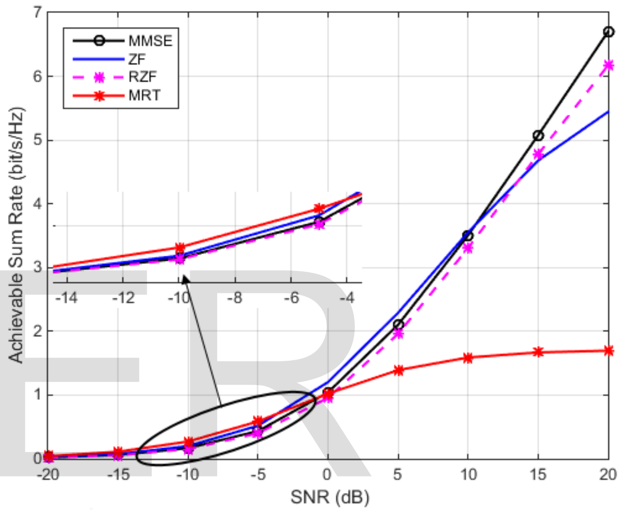


Fig. 6 an illustration of the achievable sum rate of an MU-MIMO system N=20, K=10 (with various linear precoding methods)

Figure 6 shows the achievable rate of user 1 across the entire SNR range because all of the users have the same achievable rate properties. This system consists of the number of antennas N=20 and the number of users K=10 .

The results show that MRT gives the better performance at low SNR less than -4 dB. On the other sides, ZF gives better performance at high SNR. RZF gives better performance at high SNR than ZF. MMSE perform the best achievable rate across SNR range.

Figure 7 shows the achievable rate of user 1 when the number of antennas has increased from 20 to 60. All results show that the system performance is improved.

The achievable rates of MMSE, ZF, RZF, and MRT are increased by increasing the number of antennas. Corresponding to the results in Figure 6, RZF and MMSE give the highest achievable rate to user 1. For comparison between ZF and MRT, ZF still gives the better performance at high SNR while MRT performs the higher rate at low SNR less than -5 dB. It is notable that a point, where ZF performance is better than MRT, is moved from 0 to -8 dB SNR. Increasing the number of antennas makes ZF able to be used at low SNR.

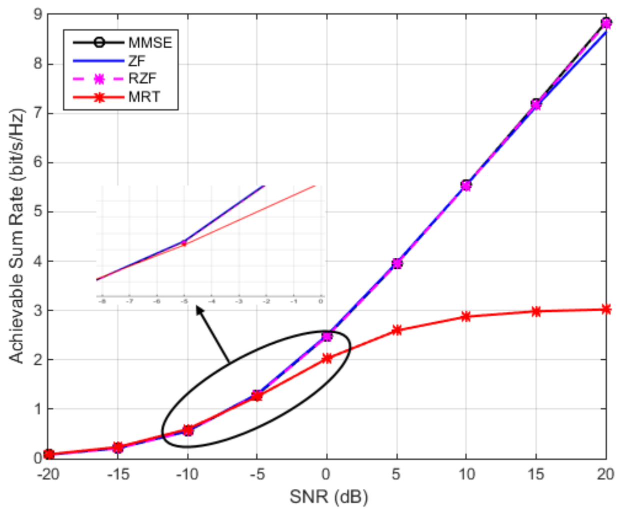


Fig. 7 an illustration of the achievable sum rate of an MU-MIMO system N=60, K=10 (with various linear precoding methods)

7 CONCLUSION AND SUGGESTED FUTURE WORK

Precoding innovation is a hot spot in the present research, through a variety of different techniques the real life in different situations of the signal to be processed to maximize the signal received by the end user. This paper discusses the linear precoding, which concerns with low complexity and can obtain better performance at the same time.

MATLAB allows us to measure two major critical metrics such as (I) bit error rate; and (II) achievable sum rate. Simulation results display that with the increase in the number of transmit antenna, the MU-MIMO communication system significantly outperforms.The research and analysis foundation for large-scale MIMO application in the 5G system. Future work includes more suitable algorithms for enhancing the BER, achievable sum rate and minimizing the BER gab between optimal and sub-optimal precoder.

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Author profile

Prof. Ahmed Shaban Samrah had received his PhD degree from the Department of Electronics and Communications Engineering, Mansoura University, Egypt in 1989. In 1977, He joined to the Electronics and Communication Department, Faculty of Engineering, Mansoura University. He has more than 15 published papers in indexed and international peer reviewed journals in communication networks field.

Prof. Mohamed.A. Mohamed received the Ph.D.degree in Electronics and Communications Engineering from the Facultyof Engineering-Mansoura University-Egypt by 2006. After that he worked asan assistant professor at the electronics& communications engineering department, then awarded the associateprofessor degree in 2012 until now. He has 91 publications in various international journals and conferences. His current research interests are in multimedia processing, wireless communication systems, and field programmable gate array (FPGA) applications. I had awarded the best Ph.D. thesis at Mansoura University at 2007. He is the executive director of scientific computing center and the consultant for IT in Mansoura University.

Assos. Prof. Haythem H. Abdullah received a BSc. degree in Electronics and communication engineering from the University of Benha, Egypt in 1998 and received his M.Sc. and Ph.D. degrees from Cairo University in 2003 and 2010, respectively. His M.Sc. is dedicated to the simulation of the dispersive materials in the FDTD and its application to the SAR calculation within the human tissues. He has a lot of publications in IEEE and various international journals and conferences. His current research is dedicated to antenna and microwave devices design and implementation, RFID systems, and recently in MIMO communication system. He is also, sharing consultancy to the air defense military force in designing antennas for their military usages.

Dr. Ahmed abo talb had received his PhD degree from the Department of Electronics and Communications Engineering, Mansoura University, Egypt in 1985. In 1978, He joined to the Electronics and Communication Department, Faculty of Engineering, Mansoura University. He has many published papers in communication networks field

Eng. Rania hamdy Elabd received the M.Sc. in Communications and Elecronics Engineering from the Facultyof Engineering-Mansoura University-Egypt by 2013 and the B.Sc. degree in Electronics and Communications Engineering from the Faculty of Engineering-Mansoura University-Egypt by 2008. He worked as an assistant lecturer at new Damietta Higher Institute of Engineering and Technology - Eygpt. Her current research interests are in wireless communication systems.