Evolution in Electrical and Electronic Engineering Vol. 3 No. 1 (2022) 008-017
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Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Performance of Linear Precoding Techniques in Massive MIMO System Over Fading Channels

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DOI: https://doi.org/10.30880/eeee.2022.03.01.002
Received 26 January 2022; Accepted 30 March 2022; Available online 30 June 2022

Abstract: Massive Multiple Input Multiple Output System (MIMO) aims in the 5G communications networks to increase performance and spectral efficiency. However, Multi-User Interference (MUI) is created when a User Terminal (UT) is found near another cellular network User Terminal (UT). In this research, non-linear precoding can be used to address this problem. However, non-linear precoding has higher implementation complexity than linear precoding techniques. Therefore, this project proposes to apply linear precoding techniques as it has a lower computational complexity. Linear precoding is more straightforward, and it has nearly optimal performance. This study simulates the mathematical model linear precoding techniques for a massive MIMO system using MATLAB. Then, to compare the performance of linear precoding in terms of bit error rate (BER) and Sum rate over Rayleigh fading channel and Rician fading channel are evaluated. Zero Forcing and Regularized Zero Forcing precoding technique performs better than Matched Filter in both Rayleigh fading channel and Rician fading channel. Performance of massive MIMO downlink channel over Rayleigh fading channel is outperforming than Rician fading channel.

Keywords: Linear Precoding Techniques, Massive MIMO, Fading Channels

1. Introduction

MIMO (Multi-Input Multi-Output) communication systems deliver very high data rates with low error rates. Multiple-input, multiple-output, or MIMO, could be a communication technique that employs multiple antennas at each the transmitter and receiver to boost communication performance. Smart antenna technology comes in a variety of forms [1]. The desire of high data rates, measured in bits per second (bps), and great spectral efficiency, considered in bps per hertz (Hz), has been a key driver in the constant development of mobile communication systems. MIMO technology has sparked a lot of interest in the wireless sector because it enables significant increases in data speed and link range without requiring extra capacity or transmit power. Increased spectral efficiency (more bits per second per hertz of bandwidth) and connection dependability or diversity are used to achieve this

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(reduced fading). MIMO is a hot topic in worldwide wireless research because of these characteristics [1].

Massive MIMO (multiple-input multiple-output) wireless technology utilises a high number of antennas, with an order of magnitude more than that of present LTE systems, and thus is an obvious contender for 5G networks. 5G massive MIMO, is a major element of the latest mobile communications technology. It would allow huge improvements in performance and storage capacity, the latter of which is a key necessity for 5G because data use is growing rapidly, identification of specific increased network capacity [2].

In the MIMO massive system, several antennas square measure endlessly utilized by the base station to serve 10 users or mobile subscribers (MSs) within the same band over ancient MIMO systems, massive MIMO offers many benefits. The advantage of massive MIMO is the latency on the air interface is reduced significantly. Figure 1 shows the massive MIMO for downlink channel.

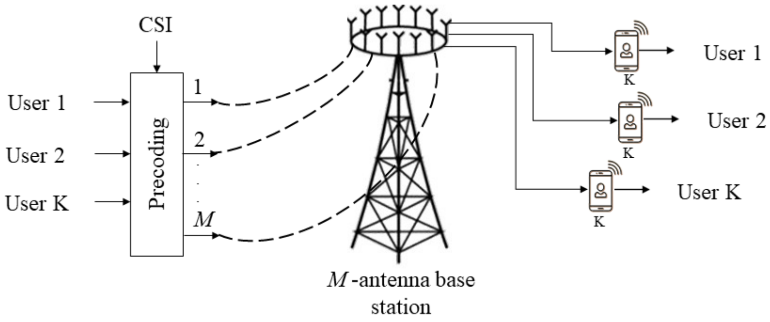


Figure 1: Massive MIMO for downlink channel [3]

2. Methodology

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Methods

Project flowchart is illustrated in **Figure 2**. In order to choose the system model parameters, a related literature analysis on precoding systems is conducted such as Channel Model, Modulation Techniques, Noise Interference and previous research paper that related of massive MIMO linear precoding techniques.

For the first part, the system model of Massive MIMO is single-cell downlink and other assumptions of the suggested method are chosen such as the algorithm massive MIMO method will be simulated. The proposed precoding methods only linear precoding and the suggested algorithm is Bit Error Rate and sum rate for massive MIMO single-cell downlink are derived. After that, simulate the algorithm linear precoding with the algorithm of channel fading such as Rayleigh channel fading and Rician fading channel. The suggested technique evaluates the performance of linear precoding using the MATLAB simulation Software. The suggested Bit Error Rate (BER) and Sum Rate algorithm to assess the system is linear precoding performance with the parameter from 0 until 30. If the result and the simulation are not satisfactory, the result is changed and simulated again with the performance of linear precoding approaches. If the results are satisfactory, the performance of the suggested algorithm linear precoding approaches for the MIMO single Cell Downlink will be carried out.

The methodology consists of a workflow that involves in this project. The research methodology is starting with a literature review to identify the problem statement and develop the research method. The flow chart representation of the research methodology is shown in Figure 2:

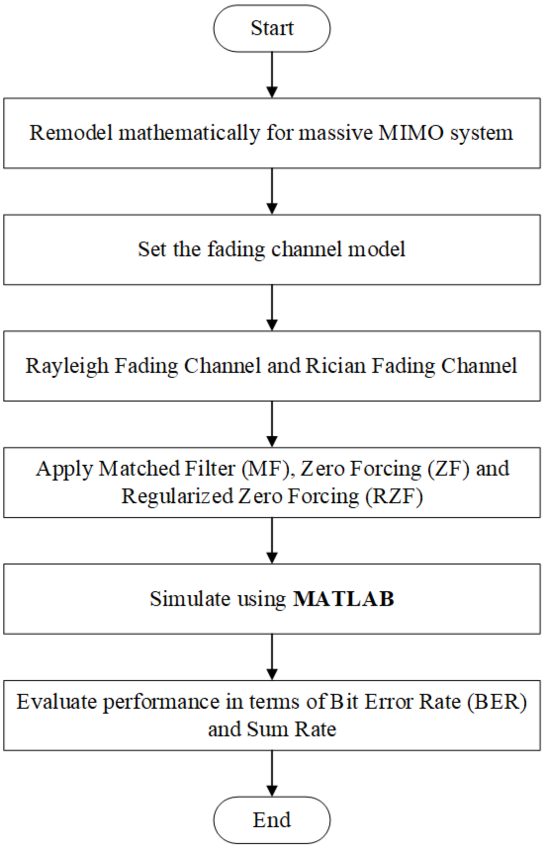


Figure 2: The process flow of the Performance of a massive MIMO system in eliminating multiuser interference over fading channels

2.2 Equation of linear precoding over fading channels

This project is assumed to have a Single-Cell downlink massive MIMO system, which consists of a central BS = 128 with a large number of antennas broadcasting to various users =8, 16 and 32 over the same spectrum at the same times. Let M be the number of antennas at the BS and K be the number of users with a single antenna.

During downlink transmission, the transmitted signal vector for the K users, where M > K, may be written as

$$x = \sqrt{\rho}\boldsymbol{W}\boldsymbol{s} \qquad \textit{Eq. 1}$$

where $\boldsymbol{W} \in \mathbb{C}^{M\times K}$ is the linear precoding matrix, $\mathbf{s}\ \mathbb{C}^{\mathbf{K\times 1}}$ denotes the transmitted source information prior to precoding, and ρ is the average transmit power at the BS. M and K are both huge in this case, and their ratio is considered to be constant. $\boldsymbol{W}$ is a function of the channel matrix, which is denoted by $\mathbf{H} \in \mathbb{C}^{M\times K}$. The transmitted source signal's power is balanced, for example, $||\mathbf{s}||^2 = 1$. $\boldsymbol{W}$ is selected in such a way that $\mathrm{tr}\,(\boldsymbol{W}\boldsymbol{W}^{\mathbf{H}}) = 1$ satisfies the power restriction at the BS. The downlink channel in TDD mode is just the transpose of the channel matrix $\mathbf{H}$. As a result, the signal set received at K terminals are

$$y = \mathbf{H}^T x + n = \sqrt{\rho}H^T\mathbf{W}s + n \qquad \textit{Eq. 2}$$

where $\mathbf{n} \in \mathbb{C}^{\mathbf{K\times 1}}$ captures interference and noise, and $\forall k \in \{0, 1, \ldots, K-1\}$, each element follows $\mathbf{n}_k \sim CN\,(0, \sigma)$. Precoding processing, as can be seen from Eq. 2, has a significant influence in achieving downlink performance. In this project also assume a Rayleigh block fading channel, in which each channel vector in $\mathbf{H}$ such as h_k follows $h_k \sim \mathbb{C}N\,(0_{M\times 1}, \frac{\Phi}{K})$, with $\mathbf{\Phi} \in \mathbb{C}^{M\times M}$ being the limited norm channel covariance matrix as $M \rightarrow \infty$. Thus, we have $\mathrm{tr}(\mathbf{\Phi}) \propto \frac{M}{K}$.

A. Equation for Linear precoding Techniques

1. Matched Filter (MF)

The conjugate transpose of the downlink channel matrix is utilised to generate the matched filter (MF) precoder.

$$\boldsymbol{W}_{\mathrm{MF}} = \sqrt{\alpha}\mathrm{H}^{*} \qquad \textit{Eq. 3}$$

where α is a scaling factor that is used to normalise signal power. Maximum ratio transmission (MRT) is another name for the MF precoder, which increases signal gain at the target user examine the essential performance characteristics for Single-Cell Matched Filter precoding, such as attainable sum rate and total downlink transmit power.

2. Zero Forcing (ZF)

Zero forcing (ZF) precoding is another type of basic precoding solution that reduces interference by delivering the signal in the direction of the intended user while nulling in the direction of other users. The ZF precoder may be located by using

$$\mathbf{W}_{\mathrm{ZF}} = \sqrt{\alpha}\mathbf{H}^{\mathrm{T}}\mathbf{H}^{*}(\mathbf{H}^{\mathrm{T}}\mathbf{H}^{*})^{-1} \qquad \textit{Eq. 4}$$

The term $\mathbf{H}^{\mathrm{T}}\mathbf{H}^{*}$ the diagonal members of the Gram matrix reflect power imbalance among the channels is represented by the off-diagonal components, and the mutual correlations between the channels are represented by the on-diagonal elements. When there are highly correlated channels, ZF precoding decorrelates them at the expense of channel capacity. It is the optimum precoding approach in the lack of additive noise. When additive noise is present, this precoding technique may enhance the noise impact.

3. Regularized Zero Forcing (RZF)

For MIMO wireless communications systems, the regularized zero forcing (RZF) precoder has been described as the state-of-the-art linear precoder due to its ability to trade off the benefits of MF and ZF precoders Alternative names for it, such as eigenvalue-based beamforming, reflect its popularity, Maximizing the virtual signal-to-interference-noise ratio (SINR) for beamforming, transmit Wiener filter, and signal-to-leakage-and-noise ratio (SLNR) maximizing beamforming. The RZF precoding matrix is given by and according to

$$\mathbf{W}_{\mathrm{RZF}} = \sqrt{\alpha}\mathbf{H}^{*}(\mathbf{H}^{\mathrm{T}}\mathbf{H}^{*}+\mathbf{X}+\lambda\mathbf{I}_{\mathrm{K}})^{-1} \qquad \textit{Eq. 5}$$

This is a ZF precoder with a regularization factor λ and a Hermitian non-negative matrix X. This is a ZF precoder with a regularization factor λ and a Hermitian non-negative matrix X. If $X = 0$, then Eq. 5 becomes an MF precoder when $\lambda\rightarrow\infty$ and a ZF precoder when $\lambda \rightarrow 0$. The extensions of the RZF technique with arbitrary user priorities, when the BS has statistical information about the user location, the RZF precoding matrix is modified to achieve optimality. The frequently used RZF precoder, on the other hand, is only ideal when the ratio of SINR need to average channel attenuation is the same for all users. Because the RZF precoder is frequently done by minimizing the mean square error (MMSE) between transmitted and received symbols, it is also known as the minimum MSE (MMSE) precoder. The RZF precoding matrix is computed by inverting a matrix with a relatively large dimension, especially for large M and K values.

B. Equation for fading channel

1. Rayleigh fading channel

This is used to specify the statistically time-varying character of the envelope of a single multipath component. The Rayleigh distribution may be estimated using the following formula:

$$P_{RA}\,(r) = \frac{r}{\sigma^2}\exp\left(\frac{-r^2}{2\sigma^2}\right),\ r \geq 0 \qquad \textit{Eq. 6}$$

Where, σ= rms value of the received signal, $\frac{r^2}{2}$ = instantaneous power, σ2 = before detection, the incoming signal's local average power

2. Rician fading channel

$$P_{RC}\,(r) = \frac{r}{\sigma^2}\exp\left(\frac{-r^2+-A^2}{2\sigma^2}\right),\ r \geq 0,\ A \geq 0 \qquad \textit{Eq. 7}$$

Where σ^2 is the difference between the in-phase and quadrature components and A is the amplitude of the dominant path's signal.

C. Equation for sum rate

In this project, the data rates that ZF and MF precoders may achieve are addressed, using the assumption that total downlink power is constant and equally distributed across all users. The effective rate over additive white Gaussian noise (AWGN) is calculated as a function of the signal-to-noise ratio using Shannon's theorem (SNR)

$$C = \log_2(1 + \mathrm{SNR})\ \text{bits/s/Hz.} \qquad \textit{Eq. 8}$$

In a Single-Cell downlink massive MIMO system with perfect CSI, the achievable data rate per user is

$$R_k = \log_2(1 + \mathrm{SINR}_k)\ \text{bits/s/Hz} \qquad \textit{Eq. 9}$$

where SINR_k is the SINR at the kth user. The possible sum rates for ZF and MF precoders with perfect CSI for high values of *M* and *K* are

$$R^{ZF}_{sum} = K\log_2[1+\rho((M-K)/K)] \qquad \textit{Eq. 10}$$

And

$$R^{MF}_{sum} = K\log_2\left[1+\rho\left(\frac{\rho M}{(K(\rho+1)}\right)\right] \qquad \textit{Eq. 11}$$

The logarithm's second terms are the per-user SINR equations for the MF and ZF precoders, respectively. When the number of users K and the number of BS antennae M increase dramatically, but with fixed proportion $\frac{M}{K}$, the SINRs for ZF and MF beneath defective CSI

$$\mathrm{SINR}_{ZF} = \frac{\in^2\rho\,(M-K)}{1-\in^2\rho K+1} \text{ and } \mathrm{SINR}_{MF} = \frac{\in^2\rho M}{(\rho+1)K} \qquad \textit{Eq. 12}$$

where ∈ is the reliability of the channel estimate.

The SINR of RZF precoding is illustrated in. The sum rate information rate of RZF precoding may therefore be obtained by putting the SINR of RZF into equation (15). RZF precoding outperforms ZF and MF precoding at both low and high transmission power levels. In terms of performance, the RZF precoder is comparable to the ZF precoder, but it is more efficient in terms of computation. As the number of transmit antennas grows with M > K, so do the possible sum rates of MF, ZF, and RZF precoding schemes. As a result, ZF precoding technique outperforms the MF counterpart.

3. Results and Discussion

The results and discussion section presents data and analysis of the study. The Bit Error Rate (BER) and Sum Rate performances of Matched Filter (MF), Zero Forcing (ZF), and Regularized Zero Forcing precoding techniques implemented in a massive MIMO system are discussed in these results. The performances are evaluated from 0 dB to 30 dB of SNR over Rayleigh fading channels and Rician fading channels.

3.1 Results

Figure 3,

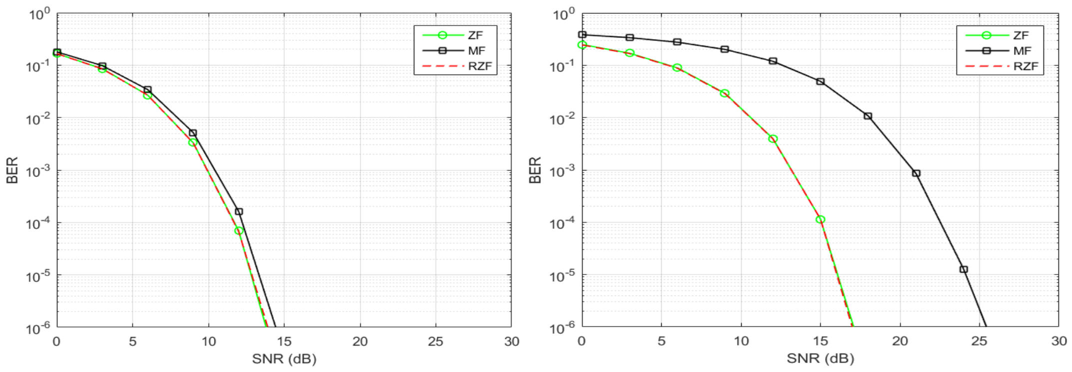
Figure **4** and Figure 5 show the BER of linear precoding techniques; MF, ZF and RZF over Rayleigh fading channel and Rician fading channel under different antenna configurations; *M*=128, *K*=8, 16 and 32 respectively. In Figure 3, ZF and RZF precoding techniques show a better performance compared to MF as these techniques need less SNR to achieve 10^{-6} of BER. Under Rayleigh fading channel, MF requires less than 1dB of SNR to achieve the same performance of ZF and RZF. However, this technique requires almost 3dB of SNR more than ZF and RZF to achieve 10^{-6} of BER. As the result comparison can see the summarizes at Table 1.

The BER performance of MF, ZF and RZF when M=128 and K=16 is shown in

Figure **4**. In this performance, ZF and RZF still outperform the MF technique for both fading channels. However, as the number of users increases from K=8 to K=16, MF requires higher SNR to achieve ZF performance. It needs around 3dB of SNR under Rayleigh fading channel and 18 dB of SNR under Rician fading channel. As the result comparison can see the summarizes at Table 2.

As the number of users increases to 32, ZF and RZF still show a better performance compared to MF as illustrated in Figure 5. The SNR that required by MF technique under Rayleigh fading is 3dB which is smaller than the amount it needs under Rician fading channel (almost 20 dB). The precoding techniques need more power to reach small BER due to the multi-user interference coming from the other users. From the observation, massive MIMO system for downlink channel gives a better BER result over Rayleigh fading channel rather than Rician fading channel. As the result comparison can see the summarizes at Table 3.

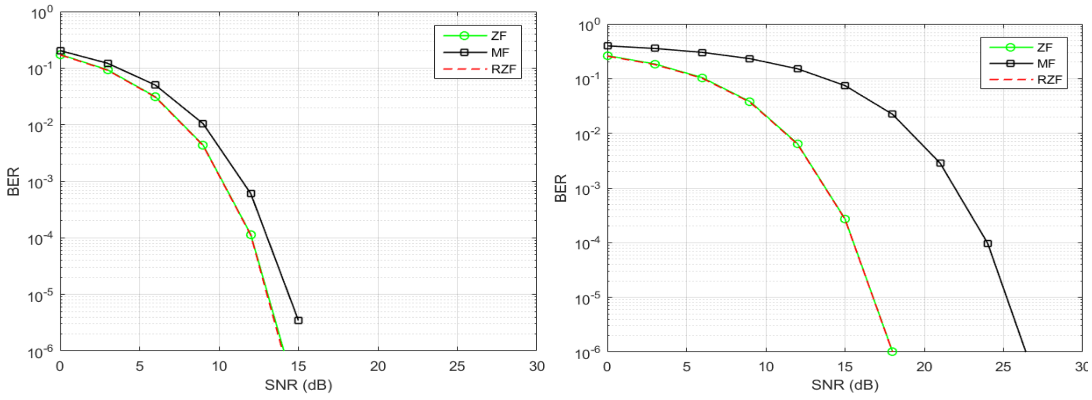
A. Bit Error Rate (BER) of linear precoding techniques over Rayleigh fading channel and Rician fading channel when M=128, K=8



(a) (b)

Figure 3: BER vs SNR of linear precoding techniques such as MF, ZF and RZF when *M*=128, *K*=8 over a) Rayleigh fading channel and b) Rician fading channel

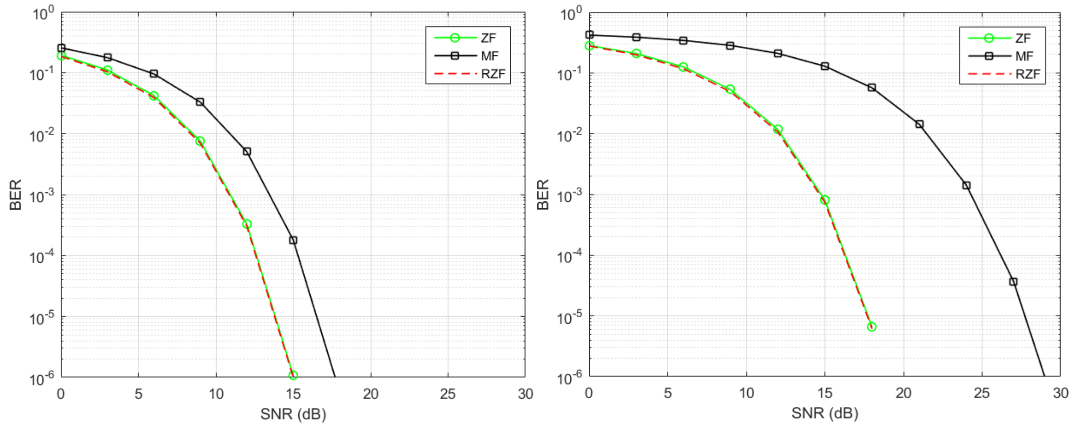
B. Bit Error Rate (BER) of linear precoding techniques over Rayleigh fading channel and Rician fading channel when M=128, K=16



(a) (b)

Figure 4: BER vs SNR of linear precoding techniques such as MF, ZF and RZF when *M*=128, *K*=16 over a) Rayleigh fading channel and b) Rician fading channel

C. Bit Error Rate (BER) of linear precoding techniques over Rayleigh fading channel and Rician fading channel when M=128, K=32



(a) (b)

Figure 5: BER vs SNR of linear precoding techniques such as MF, ZF and RZF when *M*=128, *K*=32 over a) Rayleigh fading channel and b) Rician fading channel

Table 1: The required SNR of each linear precoding technique to achieve 10^{-6} of BER when *M*=128, *K*=8

Fading channel	SNR (dB) to achieve 10^{-6} of BER		
	Zero Forcing(dB)	Regularized Zero Forcing(dB)	Matched Filter(dB)
Rayleigh fading channels	14	14	14.5
Rician fading channels	17	17	25.5

Table 2: The required SNR of each linear precoding technique to achieve 10^{-6} of BER when M=128, K=16

Fading channel	SNR (dB) to achieve 10^{-6} of BER		
	Zero Forcing(dB)	Regularized Zero Forcing(dB)	Matched Filter(dB)
Rayleigh fading channels	14	14	15
Rician fading channels	18	18	26

Table 3: The required SNR of each linear precoding technique to achieve 10^{-6} of BER when M=128, K=32

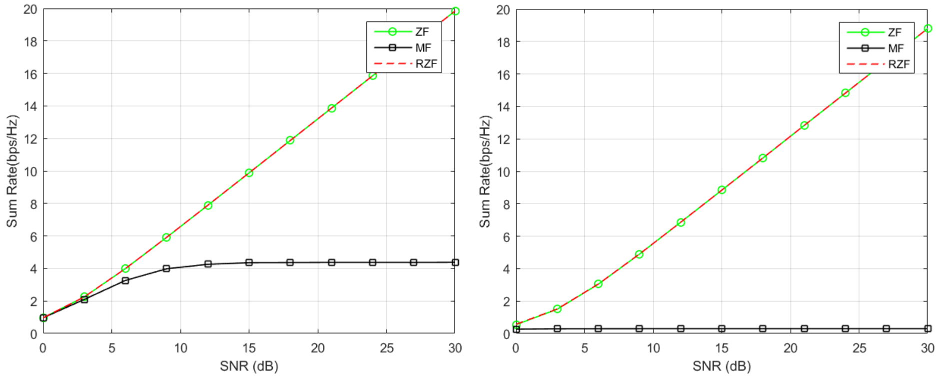
Fading channel	SNR (dB) to achieve 10-6 of BER		
	Zero Forcing(dB)	Regularized Zero Forcing(dB)	Matched Filter(dB)
Rayleigh fading channels	15	15	18
Rician fading channels	17	17	29

Figure 6, Figure 7 and Figure 8 show the Sum Rate (bps/Hz) of linear precoding techniques; MF, ZF and RZF over Rayleigh fading channel and Rician fading channel under different antenna configurations; $M = 128$, K=8, 16 and 32 respectively. In Figure 6, the sum rate of ZF and RZF increases significantly as the SNR increases from 0 to 30dB. However, the Sum Rate (bps/Hz) of the MF rises slowly in a lower SNR and it remains constant to 4 bps/Hz in a higher SNR over the Rayleigh fading channel and performs better than the Rician fading channel that only 0.1 bps/Hz.

The Sum Rate (bps/Hz) performance of MF, ZF and RZF when M=128 and K=16 is shown in Figure 7. In this performance of ZF and RZF increases significantly as the SNR increases from 0 to 30 dB. However, the Sum Rate (bps/Hz) of the MF rises slowly in a lower SNR and it remains constant to 3 bps/Hz in a higher SNR over the Rayleigh fading channel and performs better than the Rician fading channel that only 0.1 bps/Hz.

As the number of users increases to 32 ZF and RZF still show better performance compared to MF as illustrated in Figure 8. However, the Sum Rate (bps/Hz) of the MF rises slowly in a lower SNR and it remains constant to 2 bps/Hz in a higher SNR over the Rayleigh fading channel and performs better than the Rician fading channel that only 0.1 bps/Hz.

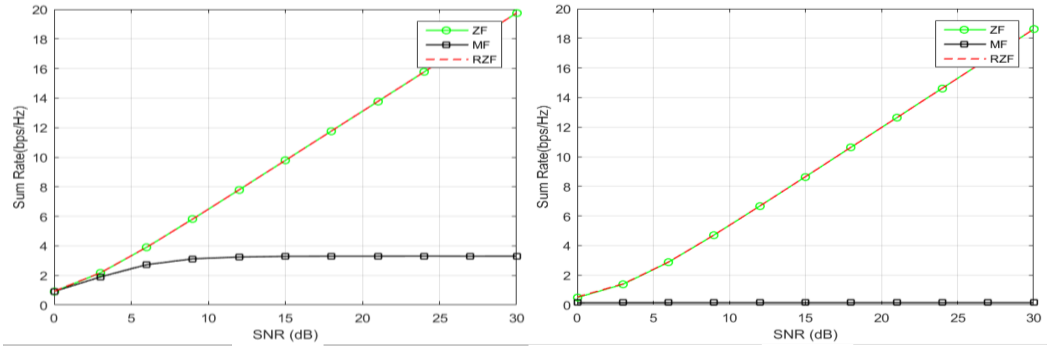
D. Sum Rate of linear precoding Techniques over Rayleigh fading channel and Rician fading channel when M=128, K=8



(a) (b)

Figure 6: Sum Rate (bps/Hz) vs SNR of linear precoding techniques such as MF, ZF and RZF when *M*=128, *K*=8 over a) Rayleigh fading channel and b) Rician fading channel

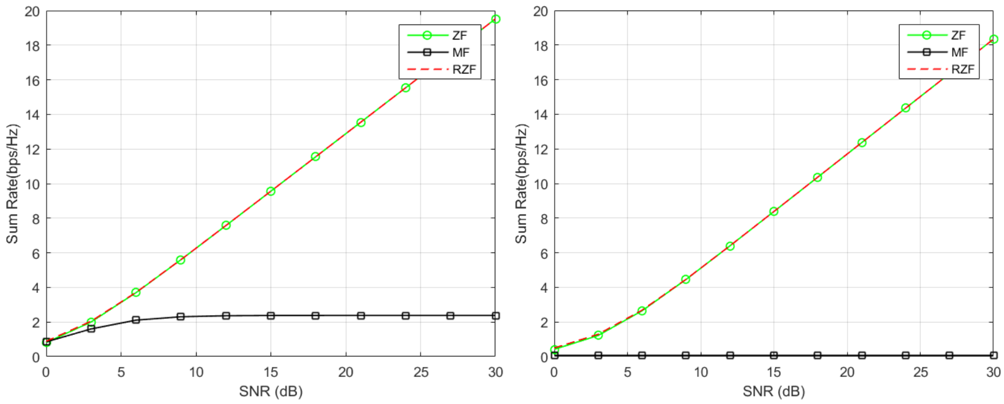
E. Sum Rate of linear precoding Techniques over Rayleigh fading channel and Rician fading channel when M=128, K=16



(a) (b)

Figure 7: Sum Rate (bps/Hz) vs SNR of linear precoding techniques such as MF, ZF and RZF when *M*=128, *K*=16 over a) Rayleigh fading channel and b) Rician fading channel

F. Sum Rate of linear precoding Techniques over Rayleigh fading channel and Rician fading channel when M=128, K=32



(a) (b)

Figure 8: Sum Rate (bps/Hz) vs SNR of linear precoding techniques such as MF, ZF and RZF when *M*=128, *K*=32 over a) Rayleigh fading channel and b) Rician fading channel

The performances of Bit Error Rate (BER) and Sum Rate of Zero Forcing, Regularized Zero Forcing and Matched Filter over the fading channel, the Rayleigh fading channel is more outperforms than the Rician fading channel.

4. Conclusion

The primary difficulty in the telecommunications sector is to transfer information as effectively as possible within determinate bandwidth, even though some data bits are lost in most cases. In this thesis, the Bit Error Rate (BER) and Sum Rate performance of Matched Filter (MF), Zero Forcing (ZF) and Regularized Zero Forcing (RZF) are compared for different type of fading channel which approach is superior through Rayleigh fading channel and Rician fading channel. 64-QAM modulation technique has been applied to modulate the transmit signals. The number of transmit data, M = 128 while the number of users, K= 8,16,32 is use to see the performance of linear precoding with different channels. As the result, Zero Forcing and Regularized Zero Forcing show a better performance compared to Matched Filter precoding technique. This is because, as compared to the Matched Filter method, the suggested algorithm successfully balances MUI and noise, particularly in the low SNR regime, where noise has a considerable influence on system performance. The result of the achievable sum rates of Zero Forcing and Regularized Zero Forcing precoding algorithms rise as the number of transmit antennas grows with M > K while for Matched Filter it maintains at bottom. So, the Zero Forcing and Regularized Zero Forcing is more outperform. BER and Sum Rate of the performance with 64 QAM signal when there are fading channels has shown the Rayleigh fading channel is more outperform than Rician fading channel.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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