

# Spectral Efficiency of MU-Massive MIMO System for Perfect and Imperfect CSI Condition

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**Abstract**— Multi User Massive MIMO (MU-Massive MIMO) is a form of multi-user large-scale antennas technology, in which hundreds numbers of antennas serve a significantly smaller number of users. This system is assumed operates over a frequency-selective and uses Orthogonal Frequency Division Multiplexing (OFDM). The system performance is observed in two conditions, the first condition is that the BTS is assumed to know channel information (perfect CSI), the second condition is that the BTS performs the channel estimation process at a certain coherence interval (imperfect CSI). BTS estimates channel information from the pilot sent by user using Minimum Mean Square Error (MMSE) estimator. Several precoding techniques are used to overcome Multiuser Interference (MUI) at the receiver, namely Maximum Ratio (MRT), Zero Forcing (ZF) and MMSE. The parameters observed in this study is spectral efficiency. From the simulation results, it can be seen that the use of a large number of antenna arrays can significantly increase the spectral efficiency. ZF and MMSE precoding works better than MRT precoding in minimizing MUI. Spectral efficiency is also affected by the channel model, where the spectral efficiency on the UR-LOS channel is higher than Rayleigh channel. In the imperfect CSI condition, the channel estimation error is getting bigger, so that the spectral efficiency will decrease and become lower than the perfect CSI condition.

**Keywords**— MU-Massive MIMO, Rayleigh, UR-LOS, Perfect CSI, Imperfect CSI, Spectral Efficiency, MRT, ZF, MMSE.

## I. INTRODUCTION

In recent years, Multiple Input Multiple Output (MIMO) technology has been developed to support the development of high-speed wireless communication system. This technology has better performance than Single Input Single Output (SISO). This concept becomes the background for the development of Massive MIMO system. Massive MIMO system is a system that uses a very large number of antennas on the BS, the antennas can be hundreds or even more [1]. By using massive antenna elements, the spectral efficiency and energy efficiency will be significantly increased, compared to the small-scale MIMO system.

Multi User Massive MIMO (MU-Massive MIMO) is used to serve multiuser simultaneously. Hundreds of antennas on a BS serve tens of users at same time and frequency resources, where each user uses single antenna. The advantages of single antenna user are that it is inexpensive, simple and uses more efficient power, but each user still get a high throughput [1]. The design and analysis of the Massive MIMO system is an interesting topic to study [2]-[5]. Some advantages of Massive MIMO system compared to conventional MIMO are, only BS

that needs to estimate the channel, the number of BS antennas is much larger than the number of users, and simple linear processing techniques can be applied both on the uplink and downlink side [6]. In order to implement MU-Massive MIMO system which represents the real conditions, Channel State Information (CSI) on the BS or user side is required. CSI is not only useful for obtaining high SNR on the user side, but also reducing interference generated by other users in a cell. However, channel estimation will be very complex because it is proportional to the large number of BS antennas, hence some previous research on Massive MIMO system assumed perfect CSI condition on both the BS and the user side [7]-[9]. In actual condition, the channel response can change at any time according to the propagation environment, so that the channel estimation is needed. Imperfection of the channel estimation process due to channel estimation error is known as imperfect CSI condition, because BS only know the noisy version of the channel.

We assume that the system works on TDD operation because uplink and downlink channel are reciprocal. BS can obtain CSI from the uplink pilots training sent by users. The number of transmitted pilots is proportional to the number of users which is much smaller than the number of BS antennas. Then BS uses CSI to precode the transmitted signal in order to reduce Multi User Interference (MUI). The downlink spectral efficiency in a cell really depends on the precoding capability to reduce interference between users [10]. Form [1,12], it is shown that the use of large-scale antennas on the BS will increase spectral efficiency without bound. Hence, the use of a massive number of antenna elements with constant number of users will significantly increase the spectral efficiency.

This paper analyses single cell MU-Massive MIMO communication system with a downlink scheme at Rayleigh and Uniformly Random Line of Sight (UR-LOS) channel. Because these channels represent very different propagation conditions. Rayleigh has rich scatterers, while UR-LOS has no scatterers at all. In practical terms, we want a channel model that includes these conditions. By knowing performance of Massive MIMO in these two channel conditions, we can estimate Massive MIMO performance on other channel models. We also observe the performance of several different precoding scheme on these two channel types, which are Maximum Ratio (MRT), Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) linear precoding.

This system is assumed to be operated over a frequency-selective channel and uses Orthogonal Frequency Division

Multiplexing (OFDM). We investigated the performance in specific conditions. First, we assume that the BS knows the channel information state (perfect CSI condition). And second, BS estimates the channel at a certain coherence interval (Imperfect CSI condition) using MMSE estimator. The parameters that will be observed are Bit Error Rate (BER) and Spectral Efficiency (SE).

Notations: Uppercase and lowercase bold letters denote matrices and vectors.  $\mathbb{E}\{\cdot\}$  denotes expectation operator. For a matrix  $\mathbf{H}$ , we denote the superscripts  $(\cdot)^T$ ,  $(\cdot)^H$  as transpose, and Hermitian matrix operation, respectively. While  $\text{tr}(\mathbf{H})$  is trace of matrix  $\mathbf{H}$  and  $\mathbf{I}_K$  is  $(K \times K)$  identity matrix. The entries of  $k$ -th row and  $m$ -th column of matrix  $\mathbf{H}$  is denoted by  $[\mathbf{H}]_{k,m}$ .  $\mathbb{C}$  represents complex number, while  $\mathcal{CN}$  represents complex normal random variable. The accent  $|\cdot|$  denote magnitude of a complex number.

## II. SYSTEM MODEL

The downlink system of single cell MU-Massive MIMO is shown in Fig. 1. This system is assumed work on a frequency-selective channel, therefore OFDM technique is used to overcome Inter-symbol Interference (ISI). BS is equipped with  $M$  number of antennas and simultaneously serves  $K$  number of users, each user uses a single antenna, where  $M$  is much larger than  $K$ .

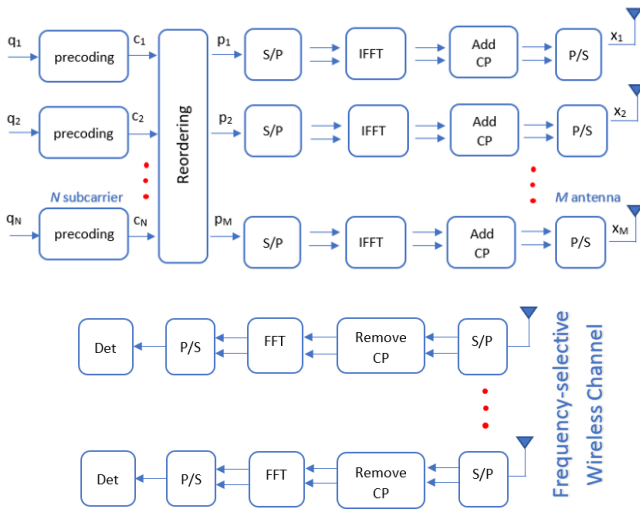


Fig. 1 System model of MU-Massive MIMO downlink scheme.

The total number of OFDM subcarriers is denoted by  $N$  where  $N$  consists of subcarriers designed for data transmission ( $N_d$ ) and subcarriers for guard band ( $N_g$ ) in order to reduce out-of-band radiation. Signal vector  $\mathbf{q}_n \in \mathbb{C}^{K \times 1}$  contains QAM modulated symbols at  $n$ -th subcarrier for  $n \in N_d$ , and no signal transmitted at guard band  $\mathbf{q}_n \in 0^{K \times 1}$  for  $n \in N_g$ .

In perfect CSI condition, we assumed that BS already knows the CSI and uses it to precode the transmitted signal. We focus on analyzing the system performance under Rayleigh and UR-LOS channel. The first channel considered is Rayleigh channel where there is no direct line of sight path. The matrix  $\mathbf{H}_{RL} \in \mathbb{C}^{K \times M}$  is a time-domain channel response in Rayleigh channel associated with  $L$  number of channel taps, where  $l = 1, 2, \dots, L$ . This matrix contains complex normal random variables  $[\mathbf{H}_{RL}]_{k,m} \sim \mathcal{CN}(0, \sigma_l^2)$ , here  $\sigma_l^2$  is power delay profile at  $l$ -th path. The second channel condition considered is UR-LOS where there is no local scatterer

between BS and users. And all users are in line of sight to the BS antennas. The UR-LOS time domain channel response between  $k$ -th user and BS is described below [10]:

$$\mathbf{h}_k = \sqrt{\beta} [1 \ e^{2\pi j d_H \sin \theta_k} \ \dots \ e^{2\pi j d_H (M-1) \sin \theta_k}]^T \quad (1)$$

Here  $\mathbf{h}_k$  is channel response associated with  $k$ -th user,  $\beta$  is large-scale fading coefficient,  $d_H$  is array spacing and  $\theta_k$  is angular position of each user which is measured relative to array boresight. Then,  $\mathbf{h}_k$  can be expressed as a matrix.

$$\mathbf{H}_{UR-LOS} = \begin{bmatrix} h_1^1 & h_1^2 & \dots & h_1^M \\ h_2^1 & h_2^2 & \dots & h_2^M \\ \dots & \dots & \ddots & \dots \\ h_K^1 & h_K^2 & \dots & h_K^M \end{bmatrix} \quad (2)$$

BS will only transmit the precoded signal at the specified angle of users. User position is random and  $\sin(\theta_k)$  is uniformly distributed at interval  $[-1, 1]$ . BS uses Uniform Linear Array (ULA) antennas. Where ULA can only detect the user position uniquely at intervals  $[-\pi/2, \pi/2]$ .

Channel matrix is assumed to be constant at certain coherence interval. In the imperfect CSI condition, BS needs to estimate the channel response. The channel estimation can be obtained from training pilots which is transmitted by all users. At each coherence interval, each user transmits orthogonal pilot sequences at length  $\tau_p$ . The transmitted pilot is a unitary matrix  $\Phi$  which is known at both ends of the link [6, 10]. The number of transmitted pilots must be greater than the number of users ( $\tau_p \geq K$ ). Collectively, all users transmit  $K \times \tau_p$  pilots [6].

$$\mathbf{X}_p = \sqrt{\tau_p} \Phi^H \quad (3)$$

Here  $\mathbf{X}_p \in \mathbb{C}^{K \times \tau_p}$  is pilot signal which is transmitted by all user, and  $\tau_p$  is length of pilot sequence. Then, BS will receive pilot signal and noise [6].

$$\mathbf{Y}_p = \sqrt{\rho_{ul}} \mathbf{H}_{ul} \mathbf{X}_p + \mathbf{W}_p \quad (4)$$

Where  $\mathbf{Y}_p \in \mathbb{C}^{M \times \tau_p}$  is received pilot signal,  $\rho_{ul}$  is uplink SNR,  $\mathbf{H}_{ul}$  is channel response to be estimated and  $\mathbf{W}_p$  is AWGN noise. Then, BS will multiply the received pilot signal with the unitary matrix  $\Phi$  in order to estimate channel response [6].

$$\mathbf{Y}_p' = \mathbf{Y}_p \Phi \quad (5)$$

The channel estimation using MMSE estimator is described as:

$$\hat{h}_k^m = \frac{\sqrt{\tau_p \rho_{ul}} \beta}{1 + \tau_p \rho_{ul} \beta} [\mathbf{Y}_p']_{mk} \quad (6)$$

Where  $\hat{h}_k^m$  is estimation channel of  $k$ -th user to  $m$ -th BS antenna.  $[\mathbf{Y}_p']_{mk}$  is  $k$ -th row and  $m$ -th column of matrix  $\mathbf{Y}_p'$ . The channel estimation error can be calculated as  $\tilde{h}_k^m = \hat{h}_k^m - h_k^m$ . We can calculate the Mean Square Error (MSE) of

the channel estimation using  $\mathbb{E}\{|\tilde{h}_k^m|^2\}$ . After BS knows channel information, then BS will use this channel matrix to precode the transmitted signals. There are several simple linear precoding techniques which have low computational complexity and nearly optimal to use since the number of BS antennas is large. In this paper we use MRT, ZF and MMSE linear precoding technique and described as follows [8]:

$$\mathbf{A}_n^{\text{MRT}} = \propto \mathbf{H}_n^H \quad (7)$$

$$\mathbf{A}_n^{\text{ZF}} = \propto \mathbf{H}_n^H (\mathbf{H}_n \mathbf{H}_n^H)^{-1} \quad (8)$$

$$\mathbf{A}_n^{\text{MMSE}} = \propto \mathbf{H}_n^H \left( \mathbf{H}_n \mathbf{H}_n^H + \frac{K}{p_d} \mathbf{I}_K \right)^{-1} \quad (9)$$

Where  $\mathbf{A}_n \in \{\text{MRT}, \text{ZF}, \text{MMSE}\}$  is precoding matrix for  $n$ -th subcarrier,  $\propto = \sqrt{1/\mathbb{E}\{\text{tr}(\mathbf{A}_n \mathbf{A}_n^H)\}}$  is a scaled factor to satisfied the total transmit power at BS,  $p_d$  is downlink SNR, and  $\mathbf{H}_n$  is channel response at  $n$ -th subcarrier which is described as:

$$\mathbf{H}_n = \sum_{l=0}^{L-1} \mathbf{H}_l \exp\left(-jn \frac{2\pi}{N} l\right), \quad n = 0, 1, \dots, N-1 \quad (10)$$

Here  $\mathbf{H}_l \in \{\mathbf{H}_{RL}, \mathbf{H}_{UR-LOS}\}$  is channel response at  $l$ -th path. Next, the symbols at each subcarrier  $\mathbf{q}_n$  are multiplied by each subcarrier precoding matrix  $\mathbf{A}_n$  and resulting frequency-domain precoded vector  $\mathbf{c}_n \in \mathbb{C}^{M \times 1}$  which contains the symbols that will be transmitted over  $n$ -th subcarrier via  $M$  BS antennas. Then precoded vector  $\mathbf{c}_n$  is reordered in order to be transmitted to the  $M$  BS antennas by using reordering process as described below.

$$|\mathbf{p}_1, \dots, \mathbf{p}_M| = |\mathbf{c}_1, \dots, \mathbf{c}_N|^T \quad (11)$$

Hence, each BS antenna transmits the signal from all subcarriers. Time-domain signal  $\mathbf{x}_m$  is obtained by performing an Inverse Fast Fourier transform (IFFT) of  $\mathbf{p}_m$ . Cyclic prefix is inserted to the time-domain signals in order to overcome ISI between OFDM symbols. After passing the wireless channel, all users receive time-domain baseband signal at discrete-time  $n$  which is represented in (7):

$$\mathbf{Y}(n) = \sum_{l=0}^{L-1} \mathbf{H}_l \mathbf{X}(n-l) + \mathbf{W}(n) \quad (12)$$

Where  $\mathbf{Y} = [\mathbf{y}_1, \mathbf{y}_2, \dots, \mathbf{y}_K] \in \mathbb{C}^K$  is received baseband vector at time sample  $n$  for all users,  $\mathbf{H}_l$  is time-domain channel response at  $l$ -path,  $\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_M] \in \mathbb{C}^M$  is transmitted signal at  $M$  BS antenna at time sample  $n$ , and  $\mathbf{w}_n \in \mathcal{CN}(0, N_0 \mathbf{I}_K)$  is Additive White Gaussian Noise (AWGN) at time sample  $n$ . Here  $N_0$  is noise power spectral density (PSD) and  $\mathbf{I}_K$  is  $K \times K$  identity matrix. After that, each user removes cyclic prefix from time-domain received signal. Then, frequency-domain signal  $\hat{\mathbf{y}}_k$  is retrieved using Fast Fourier Transform (FFT) of  $\mathbf{y}_k$ . Moreover, the received signal on  $n$ -th subcarrier and at  $k$ -th user is described as follow:

$$\hat{\mathbf{y}}_{k,n} = [\mathbf{H}_n \mathbf{A}_n]_{k,k} \mathbf{q}_{k,n} + \sum_{\substack{v=1 \\ v \neq k}}^K [\mathbf{H}_n \mathbf{A}_n]_{k,v} \mathbf{q}_{v,n} + \mathbf{w}_{k,n} \quad (13)$$

Here,  $\mathbf{A} \in \{\text{MRT}, \text{ZF}, \text{MMSE}\}$ ,  $\mathbf{H}_n$  is frequency-domain channel matrix at  $n$ -th subcarrier,  $\mathbf{q}_{k,n}$  is symbol to be transmitted over  $n$ -th subcarrier for  $k$ -th user, while  $\mathbf{q}_{v,n}$  is symbol to be transmitted over  $n$ -th subcarrier for all user except  $k$ -th user, and  $\mathbf{w}_{k,n}$  is AWGN on  $n$ -th subcarrier at  $k$ -th user. The first term on the right-hand side of (13) stands for desired signal of  $k$ -th user, the second term represents multi user interference, and the third term is AWGN. We assumed that there is only intra-cell interference and no inter-cell interference. By using (13) and assuming that  $\mathbf{q}_n \in 0^{K \times 1}$  for  $n \in N_d$ , then signal to Interference Noise Ratio (SINR) at  $k$ -th user over  $n$ -th subcarrier is defined below [1]:

$$\text{SINR}_{k,n}^A = \frac{[\rho_{dl} |\mathbf{H}_n \mathbf{A}_n|^2]_{k,k}}{\rho_{dl} \sum_{\substack{v=1 \\ v \neq k}}^K [\mathbf{H}_n \mathbf{A}_n]_{k,v} + \mathbf{w}_{kn}} \quad (14)$$

Where  $\text{SINR}_{k,n}^A$  is effective SINR for  $k$ -user at  $n$ -th subcarrier using precoding  $\mathbf{A}$ , and  $\rho_{dl}$  is downlink SNR. Then the sum spectral efficiency of all users can be obtained from the following approach [10]:

$$\text{SE} = K \log_2(1 + \text{SINR}_{k,n}^A) \quad (15)$$

The SE formula in (15) can be calculated for different channel types and precoding schemes. The downlink SE for the  $k$ -th user in a cell really depends on the used of precoding. Therefore, choosing the most appropriate precoding technique is very important. By using precoding, each signal of precoded vector is sent from all BS antennas but with a difference amplitude and phase, so that the signal will be sent directly to users.

### III. NUMERICAL RESULTS

#### A. Single Cell MU-Massive MIMO System

We simulated downlink scheme of single cell MU-Massive MIMO system which operates at a frequency of 3.4 GHz.

TABLE 1. SYSTEM PARAMETERS

OFDM Parameters	Parameter Value
Carrier frequency ( $f_c$ )	3.4 GHz
Total bandwidth ( $B$ )	5 MHz
Number of subcarriers ( $N$ )	512
Number of used subcarriers ( $N_d$ )	300
Number of subcarrier for guard band ( $N_g$ )	212
Subcarrier spacing ( $\Delta_f$ )	15 kHz
Useful symbol duration ( $T_u$ )	66.77 $\mu$ s
Cyclic prefix duration ( $T_{cp}$ )	4.9 $\mu$ s
Coherence bandwidth ( $B_c$ )	210 kHz
Coherence time ( $T_c$ )	1 ms
Delay spread ( $T_d$ )	4.7 $\mu$ s

We assumed that there is no inter-cell interference. BS uses ULA antennas with spacing between antenna elements is  $\lambda/2$ . The OFDM modulation scheme is used for data transmission, which parameters refer to LTE OFDM numerology [1,9] as shown in Table 1. We consider a Rayleigh fading frequency-selective channel with  $L = 22$  taps and has exponential distribution of power delay profile. Tapped delay lines can be used to represent sparse multipath channel for wireless communication system.

### B. Bit Error Rate (BER)

To evaluate BER of the system, we plot the BER as a function of SNR with the fixed number of BS antennas and users. BS is equipped with 100 antennas ( $M$ ) and serves 10 users ( $K$ ) simultaneously. In order to work properly, the number of BS antennas should be at least four times the number of users ( $K \leq 4M$ ) [10]. All user positions are random and uniformly distributed at interval  $[-\pi/2, \pi/2]$ .

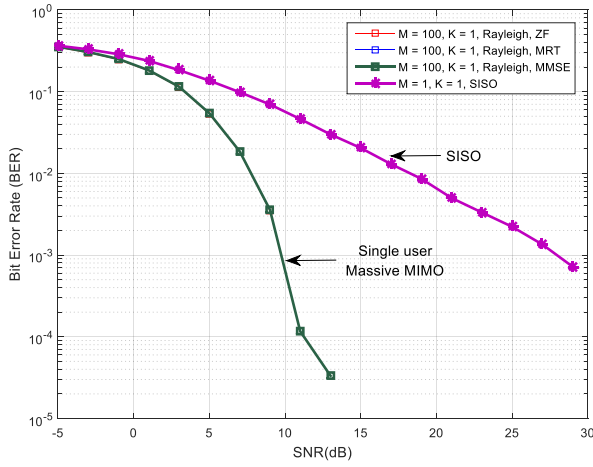


Fig. 2 BER MU-Massive MIMO at Rayleigh channel. In this example there are  $M = 100$  antennas,  $K = 1$  user for Massive MIMO system.

Fig. 2 shows BER of single user Massive MIMO system and SISO at Rayleigh channel. Based on the result of this simulation, it can be seen that BER of Massive MIMO system is lower than SISO. All of precoding schemes yield the same BER because there is no multiuser interference.

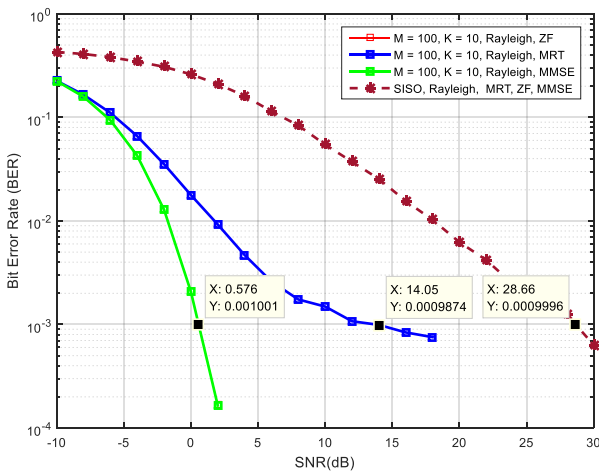


Fig. 3 BER MU-Massive MIMO at Rayleigh channel. In this example there are  $M = 100$  antennas,  $K = 10$  users for Massive MIMO system.

The BER depends on the strength of desired signal which represents as SNR. Increasing SNR means increasing the

transmit power, which results smaller BER. Fig. 3 shows BER of multiuser Massive MIMO system and SISO. For MU-Massive MIMO system,  $K = 10$  users. Several users which are served simultaneously will cause multiuser interference. All precoding schemes have different performance due to the effects of multiuser interference. The simulation result shows that ZF and MMSE yield the lower BER than MRT. Then, we investigate BER of MU-Massive MIMO system at UR-LOS channel as shown in Fig. 4. The user position is in the line of sight to the BS. All precoding scheme provide same BER under the UR-LOS channel. Overall, BER in UR-LOS channel is lower than Rayleigh channel.

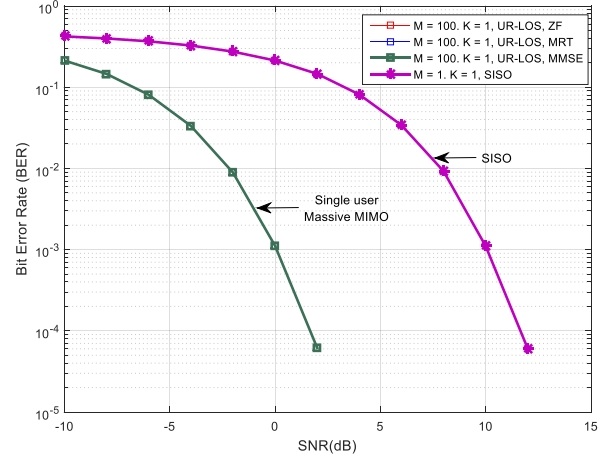


Fig. 4 BER MU-Massive MIMO at UR-LOS channel. In this example there are  $M = 100$  antennas,  $K = 1$  users for Massive MIMO system.

### C. Spectral Efficiency (SE)

Spectral efficiency is a deterministic number that can be measured in bits per time unit per bandwidth or commonly known as bit/s/Hz. Where the sum of SE is obtained from the sum of SE form all users in a cell. A high SE value is the main key objective in designing a wireless communication system. By increasing the number of antennas on the BS, the SE will be higher. In this simulation, SE is observed by increasing the number of BS antennas with a constant number of users. BS is equipped with a varying number of antennas, ranging from 50 to 300 and simultaneously serves 30 users.

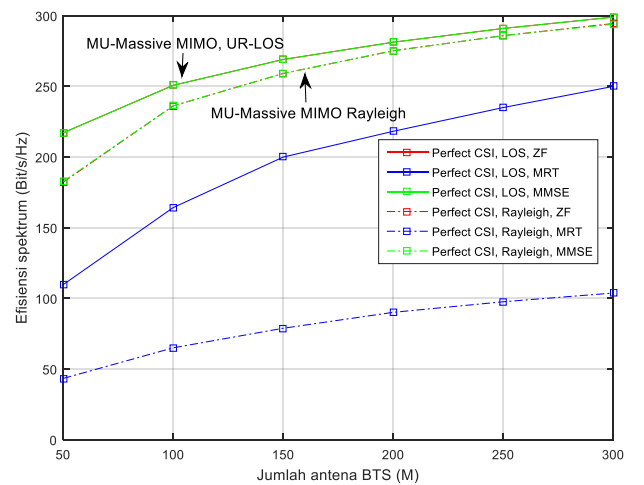


Fig. 5. Spectral Efficiency of MU-Massive MIMO at perfect CSI condition. In this example there are  $K = 30$  users and the downlink SNR = 10 dB.

The first condition is assumed to be perfect CSI condition, so that there is no channel estimation on the BS. This system is simulated in two different channel conditions, which are Rayleigh and UR-LOS. The SE as a function of antenna variation in perfect CSI conditions is shown in Fig. 5. Due to the fact that there is no channel estimation process in BS, so that BS is fully knowing the channel information without any noise and pilot contamination effects. This system works at downlink SNR of 10 dB. At high SNR, ZF and MMSE precoding work optimally and yield the same spectral efficiency both at Rayleigh and UR-LOS channel condition. The spectral efficiency of ZF and MMSE precoding also higher than MRT precoding, because ZF and MMSE precoding is better at minimizing multiuser interference than MRT. In the UR-LOS channel, the strong interference is caused by users with similar angle, so that spectral efficiency at UR-LOS channel is higher than Rayleigh.

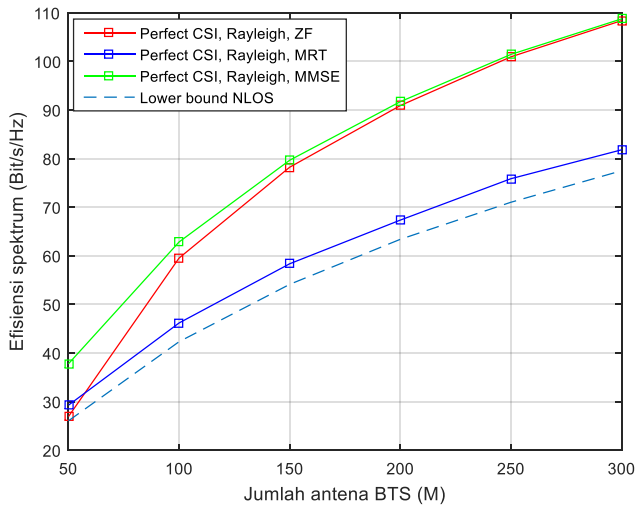


Fig. 6. Spectral Efficiency of MU-Massive MIMO at perfect CSI condition. In this example there are  $K = 30$  users and the downlink SNR = 0 dB.

Then, we simulate the system performance at downlink SNR of 0 dB. The overall system performance will decrease if the downlink SNR decreases. At low downlink SNR, MMSE precoding works better than ZF and MRT. This is because MMSE not only minimizes multiuser interference properly, but also increase SINR on the user's side, therefore the spectral efficiency will increase.

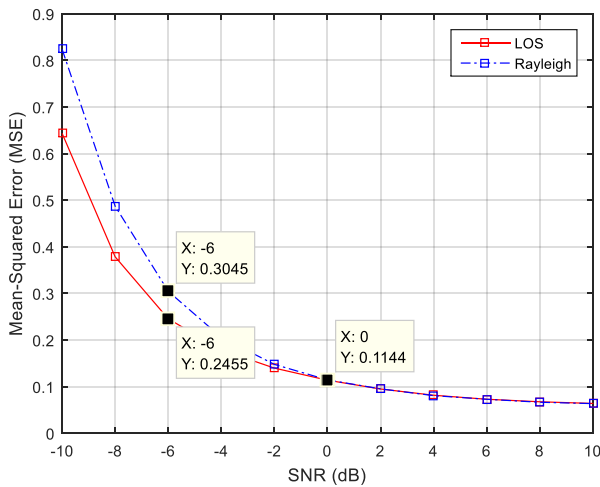


Fig. 7. Minimum Mean-Square Error (MSE) of estimated channel.

In practical, there is no perfect CSI condition, because the BS needs to estimate the channel at a certain coherence interval. Then, we focus to investigate the system performance under imperfect CSI condition. BS estimates the channel response from pilot signal transmitted by users through uplink channel. The total number of pilots transmitted by each user must be greater or equal to the number of active users in a cell, therefore each user transmits 30 symbols of pilot sequences ( $\tau_p = K$ ). This is the minimum number of pilots that can be sent by each user. The number of pilots limit how many users that can be served simultaneously. After despreading pilot signals, BS can obtain a noisy version of the channel. Then, MSE of channel estimation can be calculated and shown in Fig. 7. Channel estimation error really depends on uplink SNR at the BS, the higher the uplink SNR, the channel estimation error will be smaller. At low uplink SNR region, MSE of UR-LOS channel is lower than Rayleigh channel. MSE of these two channel conditions has the same value when the uplink SNR is above 0 dB.

Spectral efficiency of perfect and imperfect CSI condition under Rayleigh channel is shown in Fig. 8. Downlink SNR is set to 10 dB, and uplink SNR is set to -5 dB. The spectral efficiency of imperfect CSI condition is lower than perfect CSI condition due to the channel estimation error.

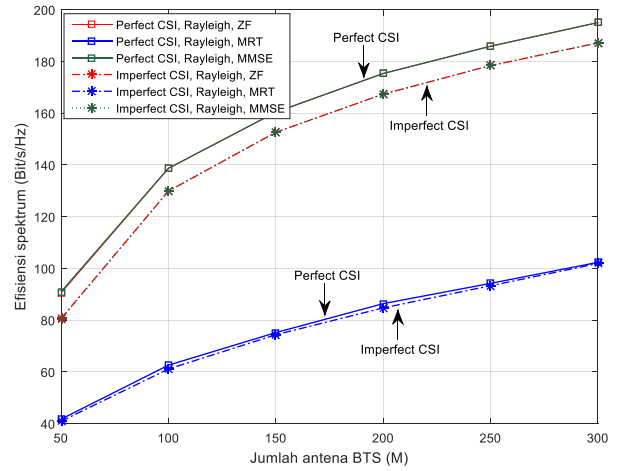


Fig. 8. Spectral Efficiency of MU-Massive MIMO at perfect and imperfect CSI condition. In this example there are  $K = 30$  users, the downlink SNR = 10 dB, and the uplink SNR = -5 dB.

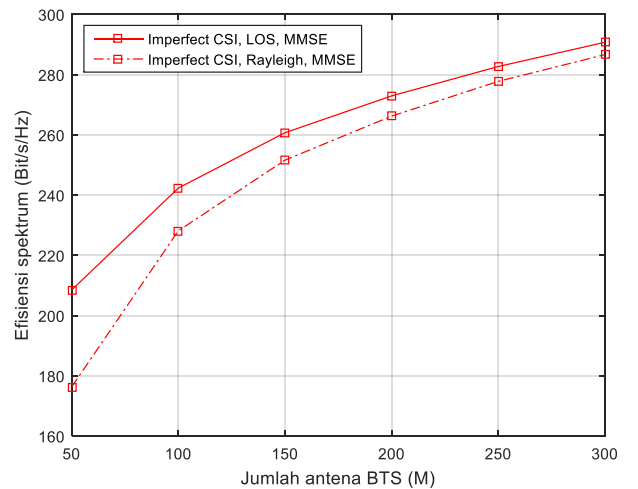


Fig. 9 Spectral Efficiency of MU-Massive MIMO at imperfect CSI condition under Rayleigh and UR-LOS channel.

The difference of spectral efficiency of Rayleigh and UR-LOS channel at imperfect CSI condition is shown in Fig. 9. Both in perfect CSI and imperfect CSI conditions, the sum SE will increase if the number of transmitter antennas increases, and spectral efficiency at UR-LOS channel is higher than Rayleigh channel.

The SE as a function of the number of users is shown in Fig. 10. We can see that the sum SE will increase as the number of users increases on condition that the number of users is still smaller than the number of BS antennas ( $K < M$ ). At 100 fixed number of BS antennas, spectral efficiency continues to increase because the number of users is still smaller than the number of BTS antenna. This condition will be different when the number of BS antennas is 30 and serves exceeds 30 users, then the SE started to decrease due to the high interference between users, and precoding is not able to overcome it. As in [10], the number of BS antennas should be much larger than the number of users, leading to an antenna-users ratio ( $M/K \geq 1$ ). This ratio makes linear precoding nearly optimal since multiuser interference is small.

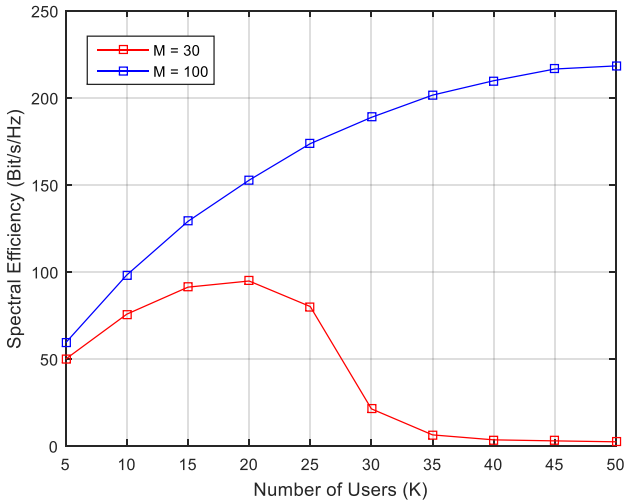


Fig. 10 Spectral Efficiency of MU-Massive with different number of users

#### IV. CONCLUSION

In this study, we investigated the performance of downlink scheme single cell MU-Massive MIMO system under perfect CSI and imperfect CSI condition. MRT, ZF and

MMSE linear precoding techniques are implemented to reduce multiuser interference. We consider linear precoding because their low computational complexity and nearly optimal to use since the number of BS antennas is large. Overall, MMSE works better than ZF and MRT in minimizing multiuser interference. The spectral efficiency increases significantly as the number of BTS antennas increases. In the imperfect CSI condition, BS estimated channel information from pilots sent by users, so that BS only knows the noisy version of channel. Under imperfect CSI condition, channel estimation error is getting bigger at low uplink SNR, so that spectral efficiency will decrease.

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