**Abstract**

**Multi User Massive MIMO (MU-MIMO) is a form of multi-user MIMO technology in which hundreds numbers of antennas serve a significantly smaller number of users. We focus to analyze the downlink system of MU-Massive MIMO which works on Rayleigh and Uniformly Random Line of Sight (UR-LOS) channel. This system is assumed operates over a frequency-selective and uses Orthogonal Frequency Division Multiplexing (OFDM). The system performance is observed in perfect CSI and imprefect CSI condition. ZF and MMSE linier precoding are used to overcome MUI at receiver. From the simulation results, it can be seen that the use of a large number of antenna arrays can significantly increase the spectral efficiency without bound. In addition, the spectral efficiency of the downlink scheme really depends on the use of precoding techniques. ZF and MMSE work equally well in suppressing the MUI at large number of antenna elements.**

***Index Terms –* Massive MIMO, Rayleigh, UR-LOS, Perfect CSI, Imperfect CSI, Least-Square Estimation, Spectral Efficiency, ZF, MMSE.**

1. **INTRODUCTION**

In recent years, Multiple Input Multiple Output (MIMO) technology has been developed to support the development of high-speed wireless communication systems. This technology has better performance than Single Input Single Output (SISO). This concept becomes the background for the development of the Massive MIMO system. Massive MIMO system is a system that uses a very large number of antennas on the BS side, the antennas used can be hundreds or even more [4]. The use of massive antenna elements can increase spectral efficiency and energy efficiency significantly, compared to the small-scale MIMO system.

In order to serve multiple users simultaneously, the Multi User Massive MIMO (MU-Massive MIMO) system is used. Hundreds of antennas on one BS can serve tens of users simultaneously, where each user uses a single antenna. The advantages of single antenna users are that it is inexpensive, simple and uses more efficient power, but each user can still get a high throughput [12].

The design and analysis of the Massive MIMO system is an interesting subject to study [a] - [d]. Some advantages of the Massive MIMO system compared to conventional MIMO are, only the BS needs to estimate the channel, the number of BS antennas is much greater than the number of users, and simple linear precoding techniques can be applied both on the uplink and downlink side [5].

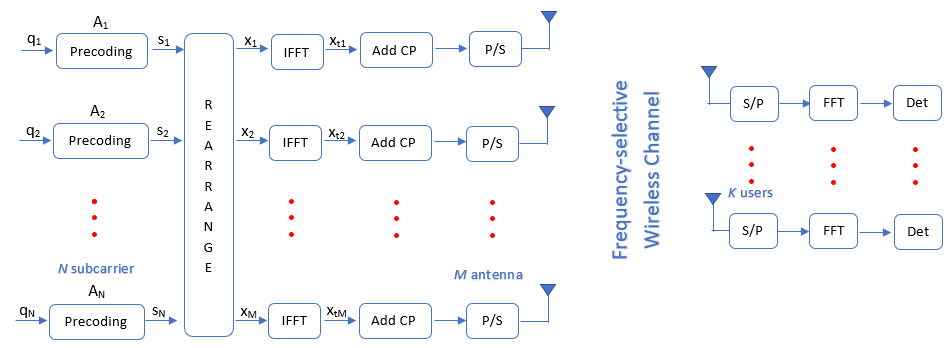
In order to implement the MU-Massive MIMO system which represents the real conditions, channel estimation on the BS or user side is required. However, channel estimation will be very complex because it is proportional to the very large number of BS antennas, hence some previous research on Massive MIMO systems assumed perfect CSI conditions on both the BS and the user side [6] [7]. In actual conditions the channel can change at any time according to the propagation environment, so estimation channel is required. This is because CSI is not only useful for obtaining high SNR on the user's side, but also in reducing interference generated by other users in a cell. The existence of a channel estimate on the BS side is known as Imperfect CSI condition, because the BS only know the noisy version of the channel.

We assume that the system works on TDD operation, so that he uplink and downlink channels be reciprocal. BS can obtain CSI from the uplink training. The number of transmitted pilots is proportional to the number of users which is much smaller than the number of BS antennas. Then BS use the CSI to precode the transmitted signal in order to reducing MUI.

This paper analyses a single cell MU-Massive MIMO communication system with a downlink scheme on the Rayleigh channel and the Uniformly Random Line of Sight (UR-LOS) channel.This system is assumed operates over a frequency-selective and uses Orthogonal Frequency Division Multiplexing (OFDM). The system performance is observed in spesific conditions. First, we assume that the BS knows channel information (Perfect CSI). And the second condition, BS estimates the channel at a certain coherence interval (Imperfect CSI). We use Least-Square Estimation method to estimate the channel respons which is obtained from the pilot sent by users. The observed parameters are Bit Error Rate (BER) and Spectral Efficiency using Zero Frocing (ZF) and Minimum Mean Square Error (MMSE) linear precoding technique .

It is shown that the use of large-scale antennas on the BS, the spectral efficiency will increase without bound. So that the use of the massive number of antenna elements with a constant number of users will significantly increase the spectral efficiency. In addition, the downlink SE for the k-th user in a cell really depends on the precoding

**System Model**



The downlink system of Multi User Massive MIMO (MU-Massive MIMO) is shown in Figure 1. BS is equipped *M* number of antenna and simultaneously serves a number of *K* users, each user uses a single antenna, where M is much larger than *K (M≫K**).* This system is assumed to work on a frequency-selective channel, so the OFDM technique is used to overcome Intersymbol Interference (ISI). Vector signal  contains QAM modulated symbols at *n-*thsubcarrier, n = 1,2,3,…*N* are total OFDM subcarriers. In fact, OFDM has subcarriers designed for data transmission and unused subcarriers for guard band . So that there are no signal transmitted on the guard band .

In perfect CSI condition, it is assumed that BS already knows channel information (CSI) and use it to precode the transmitted signal. We focus on analyzing the system performance on Rayleigh and UR-LOS channel. The matrix is time domain channel response in Rayleigh condition associated with L number of channel taps, where . The content of this matrix is

The second channel condition is Uniformly Random Line of Sight (UR-LOS) where there is no local scattering between BS and user. And all user has line of sight to the BS antennas. The time domain channel response is described as follows:

Where is channel responses associated with *k-*th user, is large-scale fading coefficient, is array spacing and is angular position of each user which is measured relative to array boresight. User position is random and is uniformly distributed at interval BS uses Uniform Linear Array (ULA) antennas. Where ULA can only detect the user's position uniquely at intervals .

Channel matrix is assumed to be constant at certain coherence intervals. In the imperfect CSI condition, BS needs to estimate the channel response. The channel estimation is obtained from the pilot which is transmitted by all users. At each coherence interval, each user transmits orthogonal pilot, which are known both end ef the links. The number of transmitted pilots must be greater than the number of users ). Collectively, all users transmit pilots. We limit the uplink transmitted signal only contains pilot signals only. This pilot signal is transmitted using *N­* numbers of subcarriers. So that the received pilot signal at ­*n­-*th subcariier is:

Where is pilot signal, is channel response to be estimated and is AWGN noise. Then BS will estimate the channel from the received pilot signal using Least Square Estimation method. The estimated channel matrix for all subcarriers is:

The channel estimation error is . So the Mean Square Error (MSE) of the channel estimation results is . After BS knows channel information, then BS uses this channel matrix to precode the transmited signals. There are several simple linear precoding techniques that can be applied to massive MIMO systems. In this paper we use Zero Forcing (ZF) and Minimum Mean-Square Error (MMSE) and described as follows

Where is precoding matiks, is downlink SNR and is identity matrix. To satisfied the total power constraint on the BS, the precoding matrix should be multiplied by a scale factor

Next, the symbols in each subcarrier are multiplied by precoding matrix. As a result is precoded vector which contains the symbol that will be transmitted to *n*-th subcarrier via *M* antenna BS. In order to transmit *N* precoded vector to *M* BS antenna, rearrange process is needed and yield reodered vector . This means that each antenna transmits the signal from all subcarriers.

A number of *M* vector are frequency-domain signals that will be transmitted over M antennas. Time-domain signal obtained by aplying an Inverse Fast Fourier transform (IFFT) of . Cyclic prefix is added to time-domain signal to overcome Intersymbol Interference (ISI) caused by transmission over frequency-selective channel.

If , and are transmitted signal, received signal and AWGN noise. All of this is in the time-domain. Then **,**  and are frequency domain matrix. Where is DFT matrix. Then, frequency-domain channel matrix is

After discarding cyclic prefix component, frequency-domain received signal at *n-*th subcarrier is:

Signal to Interfernce Noise Ratio (SINR) at *k­-*th user over *n-*th subcarrier is defined below:

While . The numerator in the equation above is desired signal for *k­*-th user. The fisrt component of the denominator is the sum of other user's power signals in the same cell, and the second component is noise variance. Then the spectral efficiency can be obtained from the following approach:

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

**Numerical Result**

1. Single Cell Massive MIMO System

We simulated a single cell Massive MIMO system which operates at a frequency of 3.4 GHz. It is assumed that the interference only comes from within the cell (intracell interference) and there is no interference from other cells (intercell interference). BS uses a Uniform Linear Array (ULA) antenna with spacing between antenna elements is . Data transmission uses OFDM modulation scheme with parameters that refer to OFDM numerology as shown in Table 1.

|  |  |
| --- | --- |
| **OFDM parameters** | **Up to 6 Ghz** |
| Number of subcarriers | 512 |
| Number of used subcarriers | 300 |
| Subcarrier spacing | 15kHz |
| OFDM symbol duration | 66.77µs |
| Cyclic perfix duration | 4.69 µs |

For Rayleigh fading frequency-selective channel conditions, the delay tap (L = 8) and has the uniform power delay profile. The path between user and BS are affected by the same large-scale fading but different small-scale fading. We assumed that large-scale fading coefficient equal to unity . Then independent Rayleigh fading can be referred as identical independent Rayleigh Fading (i.i.d rayleigh fading)

1. Bit Error Rate (BER)

To evaluate the BER of the system, we plot the BER graph as a function of SNR with the fixed number of BS antennas and user. BS is equipped with 100 antennas *(M)* and serves 20 users *(K)* simultaneously. In order to work properly, the number of BS antennas should be at least four times the number of users . All user posistions are random and uniformly distributed at interval .



BER of system at perfect CSI condition is shown in Figure 1. It can be sen that ZF has better performance than MMSE both at Rayleigh or UR-LOS channels, marked with a smaller BER at the same SNR value. While at imperfect CSI condition, BS estimates the channel from the pilot signal transmitted by the user. Each user transmits 20 pilots . This is the minimum number of pilots a user can transmit. MSE of channel estimation is shown in Figure 3.



The higher the SNR, MSE will be smaller. MSE at SNR of 10dB is 0.005. Both Rayleigh and UR-LOS have almost the same MSE value. BER system for imperfect CSI condition is shown in Figure 4. At the same SNR value, BER system with channel estimation (Imperfect CSI) and perfect CSI are not much different. However, due to the influence of noise, the BER with the channel estimation is slightly higher than the BER in the perfect CSI condition.

1. Spectral Efficiency (SE)

Spectral efficiency is a deterministic number that can be measured in bits per time unit per bandwidh or commonly known as bit / s / Hz . Where the sum SE is obtained from the sum of all users’s SE in one cell. A high SE value is the main key in designing a 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 30 to 300 and simultaneously serves 20 users. We assume SNR is 10dB, because BER on this SNR is small, which is 10-3.

SE graph as a function of antenna variation under perfect CSI conditions is shown in Fig 5. While the SE graph in the imperfect CSI condition is shown in Figure 6. In Rayleigh channel, ZF precoding yields higher SE than MMSE precoding. However, in LOS conditions, MMSE precoding works as well as ZF precoding when the number of BS antennas is increasing. This can be seen when the number of BS antennas is below 150, ZF still performs better than MSSE. But when the number of BS antennas is above 150, MMSE is almost same as ZF. Both in perfect CSI and imperfect CSI conditions, the total spectral efficiency will increaseas the number of transmitter antennas increases.





The spectral efficiency graph as a function of the number of users is shown in Figure 7. It can be seen that the SE sum will increase as the number of users increases on condition that the number of users is still smaller than the number of BS antennas . A significant increase in SE occurs when the number of users is 20 to 80. However, when the number of users is above 80, the SE graph is starting to flatten out a bit. This is because the maximum number of users that can be served by 100 BS antennas is 80 users.



Furthermore, the simulation is carried out by varying the number of users and the number of BS antennas as shown in Figure 7. When BS is equipped with 100 antennas and serves less than 100 users, the SE still increases significantly. It is different when the number of BS antennas is 30 and the user served exceeds 30, then the SE has decreased. It is different when the BS antennas are 30 and serves more than 30 users, then the SE has decreased. This is because the interference between users is large and precoding can’t overcome it.



**Conclusion**