International Journal of Research in Engineering and Innovation Vol-3, Issue-3 (2019), 183-186

International Journal of Research in Engineering and Innovation (IJREI)

journal home page: http://www.ijrei.com

ISSN (Online): 2456-6934

Performance evaluation of uplink in massive MIMO system using SC-FDMA as access scheme

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Abstract

In this paper the uplink of Massive MIMO system is analyzed for multiple number of antennas at the receiver. We used LTE standard for uplink which is SC-FDMA as access scheme and frequency domain minimum mean square error (MMSE) equalizer is utilized in simulation scenario. For post processing technique a simple, yet effective solution called *mode* method which is a simpler version of combining method is proposed. The results show that as the number of antennas increase at the receiver the symbol error rate reduces without adding any complexity in signal processing stage.

Keywords: MIMO, SC-FDMA, MMSE, Zero Forcing, Matched Filter

1. Introduction

As the time goes on the demand for high data rate is increasing and the capacity of smartphones is also increasing day by day, so it is very natural sentiment that mobile network should be upgraded accordingly. To cope up with this process there are multiple solutions suggested to modify operations at the base station (BS) or increase the number of base stations, but this would increase the deployment cost and create interference. There is another solution to this problem that is to increase the number of antennas at base station manifold. And this solution comes with its own benefits and difficulties. The benefits of having huge number of antennas at the base station are that they are not supposed to be highly sophisticated, each antennas module can be inexpensive, and they can work together to produce efficient result, hence the system would cost effective. The system can be designed in de-centralized manner, therefore if any group of antennas is not required to stay active it can be put into power-saving mode, hence the system would energy efficient.

Massive MIMO system can allow to schedule multiple terminals at the same time and frequency to achieve the higher data rate; this is known as same time-frequency resource. This gain can be achieved without using an extra spectrum [1]. Massive MIMO architecture has promised very remarkable performance in terms of efficient use of spectrum and operational complexity issues. As the base station has huge number of antennas therefore there is very even possibility to take advantage of channel reciprocity in time-division duplex (TDD) mode [2]. Other benefits of the Massive MIMO system are as follows; due to coherent beamforming/combining propagation the losses are moderated by a large array gain, the antenna array can be de-centralized as all the antennas operate independently from each other, post processing techniques are very simple and effective and lastly high beamforming resolution easily diminishes the inter-user interference.

2. Antenna Diversity Formats

The simplest transmitter and receiver antenna format have single transmit and single receive antenna as shown in Fig. 1(a). That kind of system has no antenna diversity and known as single input single output (SISO), the benefit of such kind of system is the simplicity. However, as the signal passes through wireless channel it faces several varieties of noise that could degrade signal such as thermal noise, radio-channel distortion, acoustic background noise, echo, co-channel distortion and processing noise. Therefore, there comes a need to increase the number of transmitter and/or receiver's antenna [3].

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2.1 Single Input Multiple Output (SIMO)

The transmitter has only one antenna while the receiver has two or more than two antennas as shown in Fig. 1(b). This kind of communication system is also known as receiver diversity where the receiver receives different versions of signals due to effects of fading through independent antennas and combines it after post processing which enhances the overall signal strength. The SIMO system is relatively easy to implement when the receiver is stationary and can afford more signal processing complexity, as it is not practical for handheld mobile terminal or user terminal (UE), which would require more signal processing and drain the battery faster.

2.2 Multiple Input Single Output (MISO)

The transmitter has two or more than two antennas while the receiver has single antenna as shown in Fig. 1(c). It is also known as transmit diversity. The advantage of this is that the transmitter sends the same data or signal redundantly on multiple antennas so that receiver can easily recover the data accurately while the receiver can have only single antenna. This would not increase the data rate as the same data is transmitted on each antenna. However, this would make receiver more light, simple and less power consuming equipment, which is favorable for UE. This system would make signal more resistant to channel fading and improve the performance in low signal-to-noise ratio (SNR) condition.

2.3 Multiple Input Multiple Output (MIMO)

The transmitter as well as receiver have two or more than two antennas as shown in Fig. 1(d), this provides improvements in channel robustness and overall data rate or throughput of system. However, the downside of this system is the complexity, as the channel coding is required to separate the data of different channels. Ultimately the throughput of the system is increased as new channels are created between transmitter and receiver, which is a trade-off with complexity. The advantage of having multiple antennas at both transmitter and receiver is that multiple data streams can be transmitted by either each antenna or the groups of antennas as transmit diversity, but there must be at least the same number of antennas at receiver as the number of data streams. It always helps if the transmitter antennas are more than the data streams but not vice versa, as it cannot be descrambled at the receiver even having large number of receiving antennas.

3. Massive MIMO

Massive MIMO is not just scaling up of standard MIMO. To obtain the potentials and benefits from Massive MIMO, lots of concepts and algorithms must be reinvented from standard MIMO. The format of antenna diversity in Massive MIMO for uplink is such that the UE which is transmitter has single antenna while the BS which is receiver has huge number of antennas. If there is only single user then the system would be SIMO, but communication in a cellular network is not a single show between one BS and one user. There are multiple users for each BS, which makes the system multi-user SIMO at the uplink and multi-user MISO at the downlink.

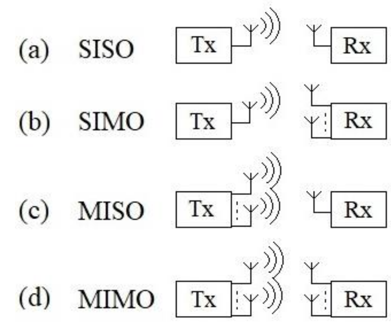

Figure 1: Antenna Diversity Formats

3.1 Uplink of Massive MIMO System Model

The transmitter operations are not modified at all due to efficient performance of SC-FDMA. UE's will function same as they function in the LTE system for uplink operation. At the receiver, which is BS each antenna will follow the standard operations of SC-FDMA in reverse manner. With the circular convolution between channel impulse response and transmit data symbols, low complexity frequency domain equalization scheme zero-forcing (ZF) linear equalization or linear minimum-mean-squared error (MMSE) equalization can be employed.

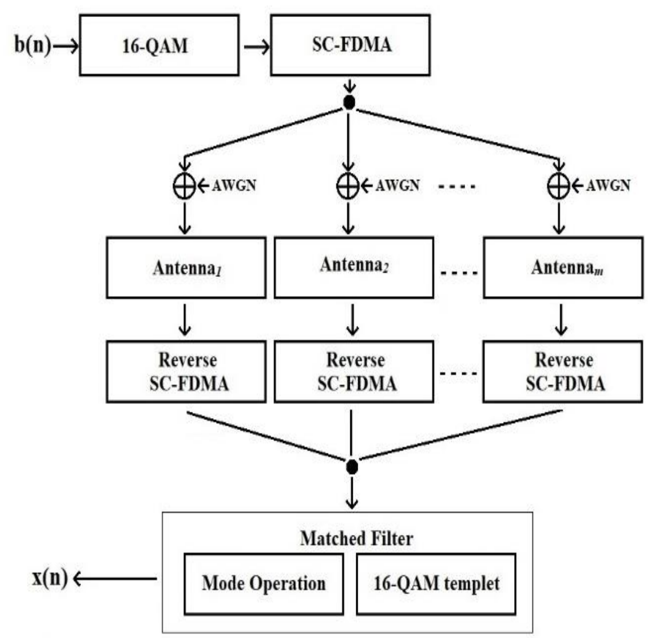

Figure 2: Uplink of Massive MIMO System Model

At the matched filter *mode* method is proposed as post processing technique to deduce the most frequent symbol received by the array of antennas. The symbols received by each antenna will be distorted, therefore the first step at matched filter would be to bring those scattered symbols to the nearest template of 16-QAM alphabet by using the boundary conditions. Due to noise, some symbols will fall into wrong inequality rage and thus they will be assigned to wrong alphabet. Then the matched filter must decide which template to take as correct one.

Mode operation is applied on the template to deduce the alphabet which is occurring most frequent on array of antennas. The mode is found by collecting and organizing data to count the frequency of each result. The result with highest number of occurrences is the mode of the set.

$16QAM_\alpha = \{\pm 1 \pm 1j, \pm 1 \pm 3j, \pm 3 \pm 3j, \pm 3 \pm 1j\}$

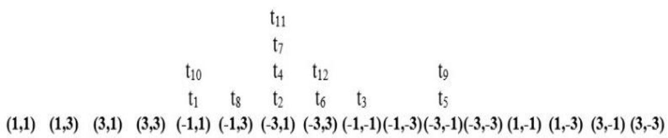

Figure 3: Mode Operation

As depicted in Fig. 3, (-3, 1) alphabet is the most occurring at the array therefore it is deduced as the transmitted symbol. In traditional combining post processing, the signals are added directly (equal gain combining) or their imperfect estimates of weights are added coherently (maximum-ratio combining) [4] which can be written as Eq. 1. Where y_n is received symbol from antenna n, h_n is the channel of antenna n and $\hat{x}$ is the solution to the Eq. 1.

$$\hat{x} = \frac{h_1^* y_1 + h_2^* y_2 + \cdots + h_N^* y_N}{|h_1|^2 + |h_2|^2 + \cdots + |h_N|^2} \quad (1)$$

In suggested mode method of combining the weight of signals is not considered, as it requires a lot of circuitry and complicated process such as used in MRC [5] hence not cost effective and it is complex method, whereas mode method is quite simple and straightforward.

4. Performance of Uplink of Massive MIMO

In the Fig. 4, symbol error rate of three receiver arrays with 4, 8 and 12 number of antennas is compared. MMSE equalizer is used at the receiver for each antenna to equalize symbols. 16-QAM modulation scheme is utilized for the following results. It is evident that the array of 12 antennas is performing better than the lesser number of antennas with lower symbol error rate. As the SNR value reaches at 7dB the symbol error rate at the array with 12 antennas is getting negligible.

In the Fig. 5, symbol error rate is compared against number of antennas with different SNR values. One thing to note is when there are only two antennas at receiver the performance is even worse than the receiver with only one antenna. This is due to mode operation at matched filter, which has this limitation. It can only be efficient when there are more than two antennas to deduce the symbol which is occurring at most of the antennas.

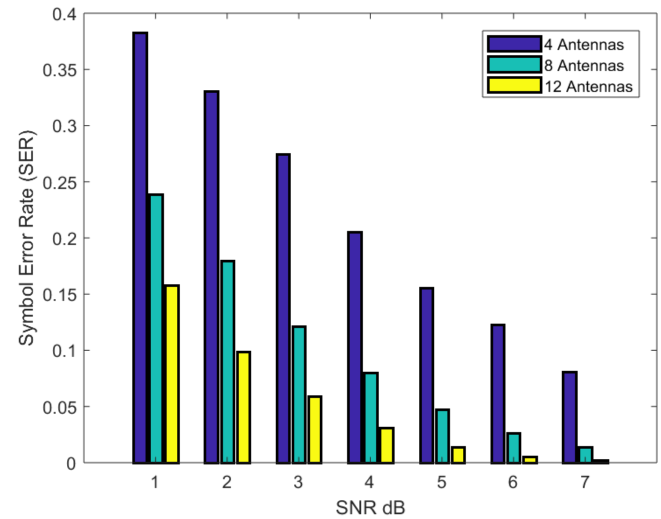

Figure 4: SER comparison of different number of antenna arrays

In addition, where there is only one antenna the probability of error is only based on the signal strength or SNR, while when there are two antennas the *mode* operation always chooses the symbol with higher value, which increases the probability of error.

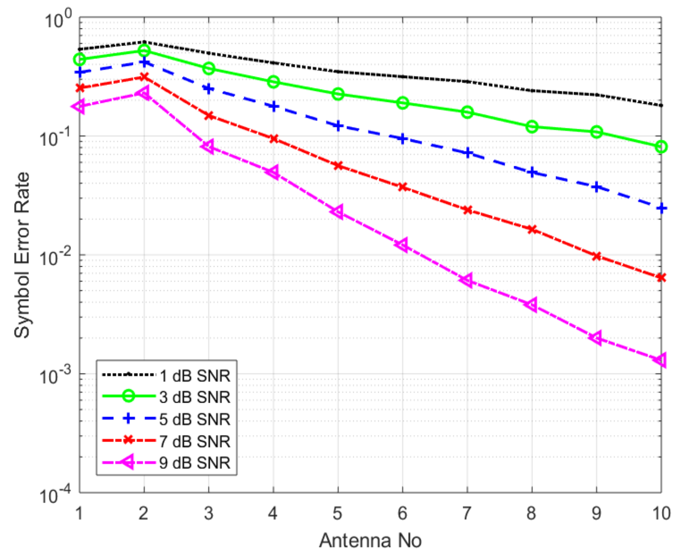

Figure 5: SER versus antenna numbers in array

5. Summary

Massive MIMO is widely studied in communication field now days due to its ability to use low-power and low-precision equipment and still able to get remarkable results. These inexpensive units can be arranged in very large numbers and can be assembled in any manner. Uplink of Massive MIMO can be designed according to the standards of LTE, but there is variation at the receiver which equips huge number of antennas and hence post processing is required. *Mode* method of combining can be fast and efficient which gives promising results.

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Cite this article as: Nandar Nyein Thu, Fahad Ahmed Memon, Gyamfi Sylvester, Changjiang Bu, Performance evaluation of uplink in massive MIMO system using SC-FDMA as access scheme, International Journal of Research in Engineering and Innovation Vol-3, Issue-3 (2019), 183-186.