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A Quantitative Comparison of Space Receive Diversity Techniques for Massive Multiple Input Multiple Output System

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***Abstract*— Mobile communication systems became an attractive technology, and nowadays there is a high demand for wireless communication. To meet the ever increasing demands in cellular communications system with high data rate; Massive Multiple Input Multiple Output (where base station equipped with large number of antennas) is a promising candidate technology for next generations of wireless communication systems. Hence the problem of severe attenuation in a multipath wireless environment makes it extremely difficult for the receiver at the base station to find out the optimum transmitted signal which leads to degrade the system performance (Signal to Noise Ratio (SNR) and Capacity). This paper gives a quantitative comparison of space receive diversity combining techniques which are Selection Combining (SC), Maximum Ratio Combining (MRC) and Equal Gain Combining (EGC) for massive MIMO system over Rayleigh fading channel for massive MIMO system. The results indicate that the improvements of Signal to Noise Ratio and capacity is achieved by increasing number of receive antennas for three combining techniques. Lastly, the comparison made between three techniques explains that MRC is a better performance than SC and EGC to combat multipath fading for next generation of cellular communications.**

***Key Words** - Massive MIMO system, Selection Combining (SC), Maximum Ratio Combining (MRC), Equal Gain Combining (EGC) and Rayleigh fading channel.*

I. INTRODUCTION

During the last years, data traffic (both mobile and fixed) has grown exponentially due to the dramatic growth of smart phones, tablets, laptops, and many other wireless data consuming devices. The demand for wireless data traffic will be even more in future. In addition, there is a growing concern about energy consumption of wireless communication systems. Thus, future wireless systems have to satisfy three main requirements: i) having a high throughput; ii) simultaneously serving many users; and iii) having less energy consumption.

Massive multiple-input multiple-output (MIMO) technology, where a base station (BS) equipped with very large number of antennas (collocated or distributed) serves many users in the same time-frequency resource, can meet the above requirements, and hence, it is a promising candidate technology for next generations of wireless systems. Also known as Very large multiple-input multiple-output (MIMO) time-division duplexing (TDD) systems [1]-[3] are currently investigated as a novel cellular network architecture with several attractive features: First, the capacity can be theoretically increased by simply installing additional antennas to existing cell sites. Thus, massive MIMO provides an alternative to cell-size shrinking, the traditional way of increasing the network capacity [4]. Second, large antenna arrays can potentially reduce uplink and downlink transmits powers through coherent combining and an increased antenna aperture [5]. This aspect is not only relevant from a business point of view but also addresses environmental as well as health concerns related to mobile communications [6], [7]. And also massive multiple-input multiple output systems has received great attention as a key technique for the increase of spectral efficiency in next generation wireless communication systems. Furthermore, the massive MIMO technique can provide high spectrum efficiency with low energy consumption, making it quite applicable to green communication systems [8]-[10].Fig (1) represents the base station equipped with large number of antennas.

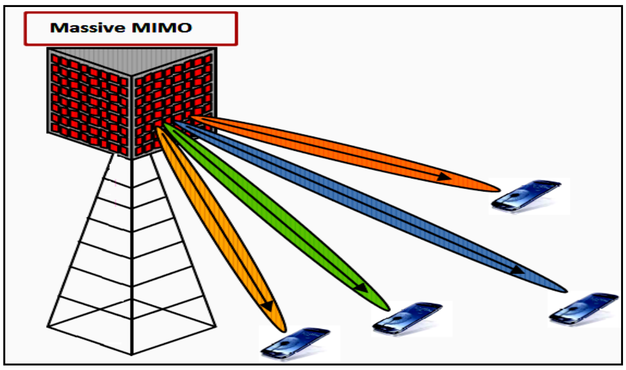

Figure (1): Base station equipped with massive MIMO antennas.

In massive MIMO system the independent links may suffer from severe attenuation in a multipath wireless environments, makes it extremely difficult at the receiver to find out the optimum transmitted signal which is affected by slow or fast small scale fading (results from Doppler shift phenomena); this leads to degrade the system performance of cellular communication.

Diversity techniques are used to mitigate degradation in the error performance due to unstable wireless fading channels, for example, subject to the multipath fading. Hence; the reliability of wireless communication depends on the quality of fading channel. In general, there is a significant probability that a signal path is in fading channel. Diversity based techniques are commonly used to combat the adverse impacts of the fading. The original motivation for applying diversity techniques is that if multiple versions of the same transmitted signal pass through independently fading paths, compared with the case of single signal path, the probability that all these versions experience fade reduces dramatically [11-13]. A wireless communication system relying on diversity techniques can guarantee reliable communication as long as one of the multiple signal paths is strong. There are various ways of realizing diversity: Time Diversity, Frequency diversity, Space diversity, Polarization diversity, Angle diversity, Pattern diversity. Multiple antennas are deployed at either the transmitting end or the receiving end to achieve diversity. The distance between the multiple antennas must be sufficiently far apart to ensure that the signals from the individual antennas face uncorrelated fading processes. Space diversity is an attractive alternative in modern scenario where bandwidth is a precious commodity. Space diversity can further be divided into receive and transmit diversity. Space Diversity refers to receiving the same signal over multiple antennas that are separated enough to create independent fading channels. To provide space diversity, multiple antennas are used at the receiver. The independent spatial channels provided by multiple antennas can be also used to carry independent data streams.

This paper presents the space receive diversity combing techniques (selection combining (SC), equal gain combining (EGC) and maximum ratio combining (MRC)) which applied for massive MIMO system to combine multiple copies of data streams by determine the two performance methods (signal to noise ratio and system capacity) with assumption of optimum transmitted signals with BPSK modulation over Rayleigh fading channel.

II. SYSTEM MODEL

Consider a receive diversity system for massive MIMO system with large number of receive antennas (N_R) and user with a single transmit antenna as shown in Fig: (2):

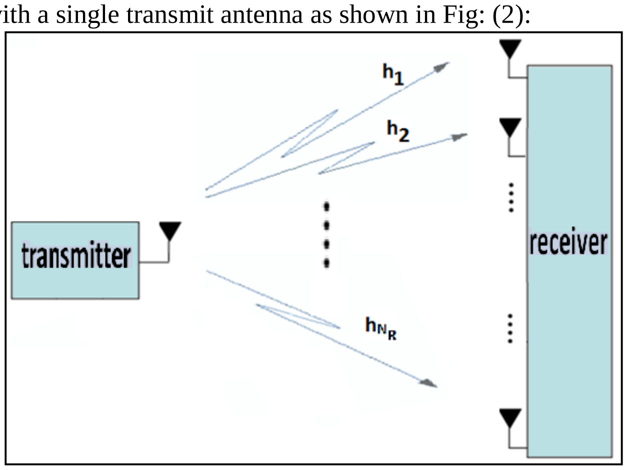

Figure 2: Space receive diversity (with M receiver antennas).

The channel matrix between transmitter and receiver is given by:

$$h = [h_1 h_2 \; ... \; h_{N_R}]^T \quad .... (1)$$

Where h denotes to channel matrix, NR represents the independent Rayleigh fading channels. Let x denotes the optimum transmitted signal with the unit variance in the channel. The received signal $y \in \mathbb{C}^{N_R \times 1}$ as written by:

$$y = \sqrt{\frac{E_X}{N_0}}\, h\, x + z \qquad .... (2)$$

Where:

y : is received signal.

x : is transmitted signal.

N_0: is noise power.

Z: zero-mean circular symmetric complex Gaussian.

The one method to quantify the system performance is Signal to Noise Ratio (SNR) (which is ratio between receive signal power to noise power) for the ith branch, which is given by:

$$SNR_i = |h_i|^2 \frac{E_X}{N_0}, i = 1, 2. \ldots . N_R \qquad .... (3)$$

Where:

SNR: signal to noise ratio.

$\frac{E_X}{N_0}$: Is required signal to noise ratio in digital communication systems.

Other method to quantify the system performance is the capacity. The capacity follows the Shannon's theorem. This theorem gives the capacity at which the transmitter can transmit over the channel. From Shannon theorem, the channel capacity is given by [14]:

$$C = \log_2(1 + SNR)(bits/s/\,Hz) \qquad ... \quad (4)$$

The received signals in the different antennas can be combined by various combining techniques. These combining techniques include selection combining (SC), maximal ratio combining (MRC), and equal gain combing (EGC); to improve the system performance of cellular communication.

- *Selection combining diversity (SC):*

At the receiver, if there are N copies of the same transmitted symbol. Then they have to combine them effectively to reliably recover the transmitted data. Consider the fading for each signal is independent. In the selection combining diversity, the receiver selects the antenna with the highest received signal power and ignores observations from the other antennas. Therefore assign weights such that for maximum power signal provide weight 1 and for rest of others weight 0 to get one significant signal at the output. For deriving the mathematical expressions for the selection combining diversity, obtain the set of weights w. To obtain the weight vector value, assume that the receiver has the required knowledge of the channel fading vector h. As each element is an independent sample of the fading process, the element with the greatest SNR is chosen for further processing Fig: (3) represent the block diagram of selection combining diversity. In the selection combining diversity, the expression instantaneous SNR with weight function can be written as [15-18]:

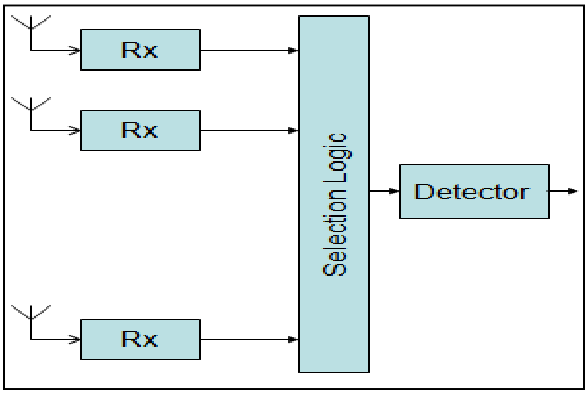

Figure 3: Selection Combining Technique.

Then the average of instantaneous SNR for SC is given by:

$$SNR_{SC} = E\{\max_i(|h_i|^2)\}.\frac{E_X}{N_0} \quad , \; i = 1, 2.....N_R \quad ..... (5)$$

- *Maximum ratio combining diversity (MRC):*

In order to maximize the output SNR of the signal, we cannot choose one signal and neglect others. So combine the signals on such a way that the output signal provides all transmitted information. In MRC, we assign the weighted bits to the signal in such a way that all the signals are strong, which is performed in the order to improve the faded signals. The branches with strong signals are further amplified and those which are week are attenuated. Then combine the signals to get output signal, which improved the performance than the selection combining diversity, however it is too complex to implement. Its weighted bit allocation process is complex and we have to know the exact signal at the receiver [19,20]. Fig: (4) represents the block diagram of maximum ratio combining technique.

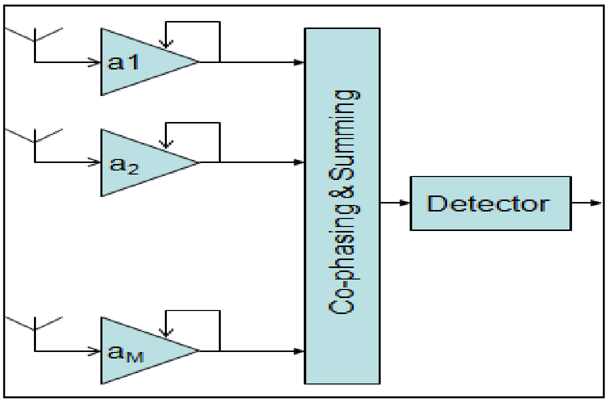

Figure 4: Maximum Ratio combining technique.

The average SNR for MRC is given by:

$$SNR_{MRC} = \frac{E_x}{N_o}\frac{|W_{MRC}^T h|^2}{\|W_{MRC}^T\|_2^2} \quad .... (6)$$

Where:

W_{MRC}^T :is weights.

- *Equal gain combining diversity (EGC):*

In some cases it is not convenient to provide for the variable weighting capability required for true maximal ratio combining. In such cases, the branch weights are all set unity, but the signals from each branch are co-phased to provide equal gain combining diversity. In this technique; it assigned the equal weights to the receiver branches which amplify the signals equally [21]. Fig (5) represents the block diagram of equal gain combining technique.

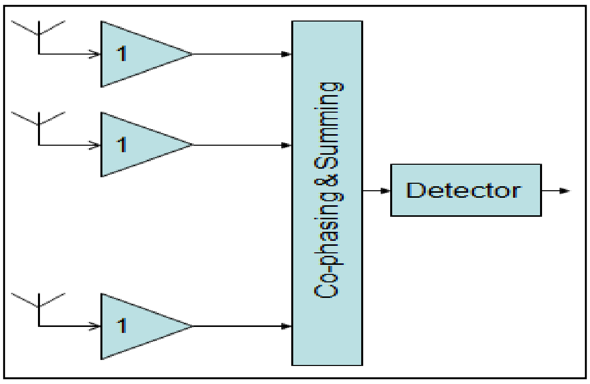

Figure 5: Equal Gain combining technique.

The mean SNR of equal gain combing is given below:

$$SNR_{EGC} = \left[1 + (N-1)\frac{\pi}{4}\right] |h_i|^2 \frac{E_X}{N_0} \quad .... (7)$$

III. SIMULATION RESULT

MATLAB tools have been used for the SNR and capacity improvements simulation. The figures (6 and 7) below show the comparison of output curves between Signal to Noise Ratio (SNR) and number of receive antenna (NR) [up to 128 and 256 respectively] of massive MIMO system for (SC), EGC and MRC; while figures (8 and 9) represents the comparison of output curves between capacity and number of receive antenna (NR) for massive MIMO system. By assume optimum transmitted signal (10^4 bits or symbols) with BPSK modulation techniques and the signal to noise ratio for digital communication (Eb/No (dB) =30).

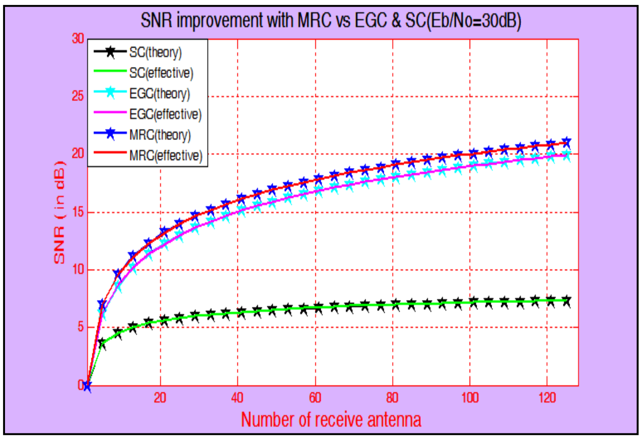

Figure 4.4: Performance comparison for SNR improvement of SC, EGC & MRC [up to 128 antennas].

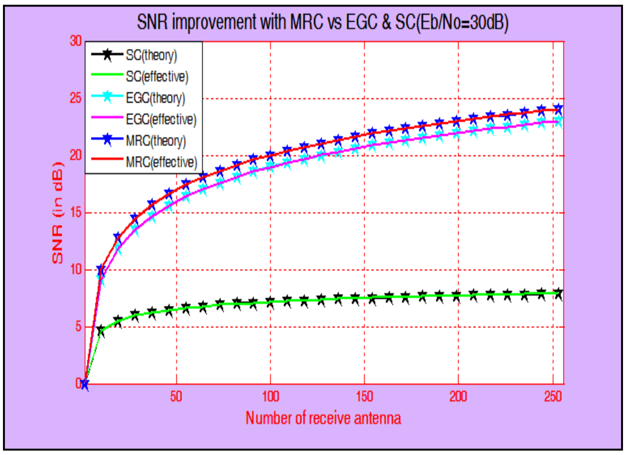

Figure 4.8: Performance comparison for SNR improvement of SC, EGC & MRC [up to 256 antennas].

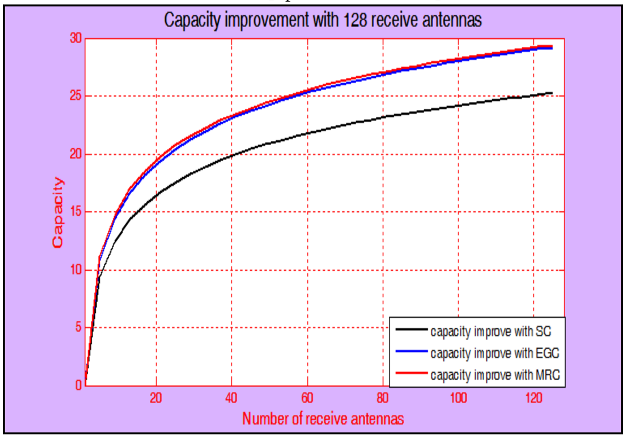

Figure 4.9: Performance comparison for capacity improvement of SC, EGC & MRC [up to 128 antennas].

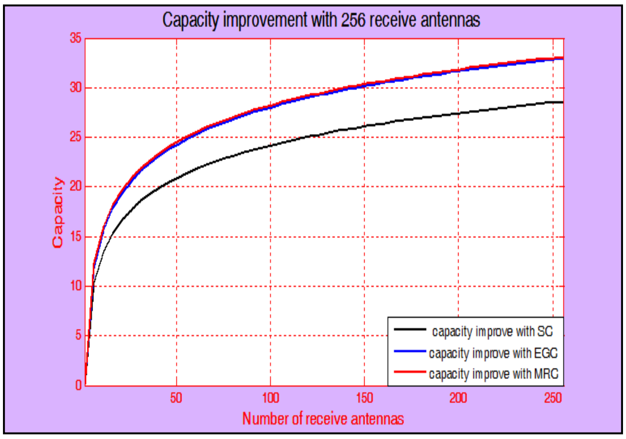

Figure 4.10: Performance comparison for capacity improvement of SC, EGC & MRC [up to 256 antennas]

Above figures indicate that increasing number of antennas and applying receive diversity techniques enhance performance of massive MIMO system. Therefore MRC give better performance versus SC and EGC for SNR and Capacity.

Table.1: give the numerical values of SNR improvements for three techniques when number of antenna from 128 to 256 with step 32 [in dB].And Table.2: give the numerical values of Capacity improvements for three techniques when number of antenna from 128 to 256 with step 32 [in dB].

Table.1: SNR gain improvement in (dB) from 128 to 256 receive antennas with step 32:

Receive antennas	nRx = 128		nRx = 160		nRx = 192		nRx = 224		nRx = 256	
SNR dB / Technique	Effective	Theory	Effective	Theory	Effective	Theory	Effective	Theory	Effective	Theory
SC	7.3534	7.3505	7.5228	7.5247	7.6701	7.6621	7.7741	7.7751	7.8634	7.8706
EGC	20.0288	20.0323	20.9988	20.9995	21.7905	21.7901	22.4576	22.4587	23.0440	23.0379
MRC	21.0749	21.0721	22.0393	22.0412	22.8327	22.8330	23.5028	23.5025	24.0840	24.0824

Table.2: Capacity gain improvement from 128 to 256 receive antennas with step 32:

Receive antennas	SC capacity(dB)	EGC capacity(dB)	MRC capacity(dB)
nRx = 128	25.3595	29.3128	29.5301
nRx =160	26.4092	30.4842	30.6924
nRx = 192	27.2667	31.4353	31.6368
nRx = 224	27.9822	32.2348	32.4312
nRx = 256	28.6012	32.9244	33.1161

IV.CONCLUSION

This study introduces a quantitative comparison of space receive diversity combining techniques for massive MIMO system over Rayleigh fading channel to compact the effect of multipath problems and select the optimum combing techniques for massive MIMO system. The simulations and results explain that; increasing the number of receive antennas enhance the system performance for wireless communication (Noise Ratio and capacity) for three combining techniques. At 128 antennas; the SNR and capacity improvement for SC, EGC and MRC (7.3534 dB and 25.3595 dB, 20.0288 dB and 29.3128 dB, 21.0749 dB and 29.5301 dB respectively). In the case of 256 antennas ;(7.8634 dB and 28.6012 dB, 23.0440 dB and 32.9244 dB, 24.0840 dB and 33.1161 dB respectively). Maximum ratio combining technique and Equal gain combining technique give better performance than selection combining technique. In contrast; the Maximum ratio combining technique is better than SC and EGC (relative to priority of non-unity weighting and co-phasing) for receive diversity in next wireless communication.

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