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Performance Evaluation of Space Receive Diversity Techniques for Massive MIMO System

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ABSTRACT

This paper presents performance evaluation of massive MIMO system in terms of signal to noise ratio (SNR) and system capacity with respect to increasing number of receive antennas at the base station for a wireless communication between a single transmit antenna of user terminal per time. The analysis performed in MATLAB simulation environment revealed that for M = 128, 256, and 512, the SNR improvement in dB achieved using selective combining (SC) was 7.31, 7.85, and 8.34 respectively, whereas for equal gain combining (EGC) and maximal ratio combining (MRC) the SNRs performance in dB were 19.79 and 20.83, 22.95 and 24, and 25.96 dB, and 27 respectively. Generally, the outcomes of simulations have proven that optimizing the number of receive antenna based on selection by changing the number of antennas at base station (BS) can provide improved SNR and system capacity.

Keywords : **Massive MIMO system, Space receive diversity techniques, Signal to noise ratio, Capacity**

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I. INTRODUCTION

In recent times, the number of user equipment (UE) connected to wireless communication has largely increased and this has resulted in increase huge data traffic over transmission channels. The number of applications that is bandwidth demanding has tremendously increased as portable smart devices are being developed and introduced in last few decades. Also, due to several communication services such as file sharing and video streaming, the limits of the current wireless networks are already being pushed [1]. As example, between the years 2000 and 2015, an increase in mobile data traffic was 400 million times, from below 10 Giga Byte (10 GB) every month to 3.7 Exa Byte (3.7 EB) each month respectively [1]. Data consumption is expected to continue in this trend and not stopping anytime soon. There is every propensity that in the next 10 years, the rate of data demand will significantly rise to an extent that the fourth generation (4G) long term evolution (LTE) will not be able to support it [1].

As wireless data traffic dramatically increases globally, existing wireless communication technology has witnessed significant demands requiring urgent attention for improvement. This state of affairs will overwhelm infrastructures of 3Gpp and 4G networks. Therefore, employing a technology that entails overlaying of small base stations (BSs) within the main network in terms of coverage demands could be a potential solution to achieving a wireless network of remarkable expansion and capacity. One of the solutions that have attracted attention regarding improving wireless system capacity is the use of large scale multiple-input multiple-output (MIMO) antenna arrangement called massive MIMO. The reduction of the size of antenna element enormously serves the requirement of massive and thus making the use of large-scale arrays a promising technology [2], [3]. Besides, increasing the number of antenna elements can provide improved performance and better signal to interference-plus-noise ratio (SINR). While conventional MIMO systems employ maxi mum of 8 antenna arrays at both transmitting and receiving sides (8×8 MIMO systems), massive MIMO and based on the prototype being implemented for 5G network can take up to 256 antennas and UE up to 32 [3]. That is massive MIMO systems have significant number of antennas at each BS, while serving a much lesser number of users [4]. Generally, the introduction of massive MIMO can ensure the realization of significant throughput (or spectral efficiency) and coverage improvement in mobile network.

II. TECHNIQUE APPLIED IN MASSIVE MIMO SYSTEM

There is significant number of studies designed to improve the performance of MIMO systems. Attempt to demonstrate that in a Rician channel, high throughput can be delivered by massive-MIMO system has made in [5]. The model of massive-MIMO network uplink with three cells that cover three base stations to solve the optimization problem of cell coverage is presented [6]. In order to meet low power demands, [7] developed a scheme for optimizing, the energy consumption, the coverage, and the position of massive-MIMO base stations within a suburban area in Ghent, Belgium. The performance of massive-MIMO in real propagation channels based on antenna selection has been determined in [8]. In [9] an 8×8 uplink antenna and 16×16 downlink antenna were used for the simulation of optimal channel estimation for massive-MIMO in LTE standard using Grey Wolf

Optimization (GWO) algorithm. Attempt was made by [10] to address the problem of coverage and capacity optimization (CCO) using group alignment of user signal strength (GAUSS) to effectively aid user for large-scale MIMO system. Lim et al. [11] conducted performance analysis of large scale MIMO for downlink and uplinks cases in which 3 radio units linked via digital unit support multiuser equipment at the cell-boundary through the same time-frequency slot. The performance of massive MIMO was analysed in terms of capacity and signal to noise ratio (SNR) for 5G wireless network using zero forcing (ZF) and maximal ratio combining (MRC) detectors by [12].

Despite the promising quality of massive MIMO technology, the independent links may experience severe attenuation in a multipath wireless channels thereby making it very difficult at the receiver to determine the optimum transmitted signal that is affected by slow or fast small scale fading. This results in performance degradation in wireless communication system. The objective of this paper is to evaluate the performance of massive MIMO system in terms channel capacity and signal to noise ratio (SNR) using different receive diversity combining schemes.

III. SYSTEM MODEL

The block diagram of the proposed massive MIMO system is shown in Fig. 1. It is a considered as a receive diversity system for massive MIMO structure with large number of M receive antennas and UE with a single transmit antenna.

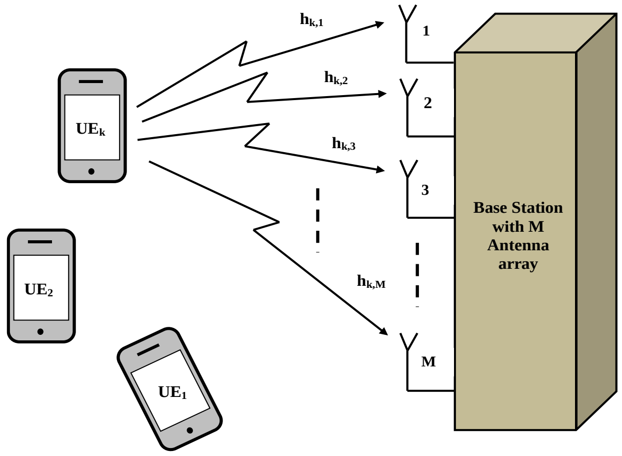

Fig. 1 Massive MIMO system

Consider a wireless network with Rayleigh fading channel comprising of M antenna array at the BS receiving from kth UE with single transmit antenna N. The MIMO channel H between the transmitter and receiver as a result of the space diversity communication of the multiple antennas at the BS is given by:

$$H = \begin{bmatrix} h_{k,1} \\ h_{k,2} \\ h_{k,3} \\ \vdots \\ h_{k,M} \end{bmatrix} \tag{1}$$

where H is the channel (gain) matrix, $h_{k,M}$ is the independent Rayleigh fading channels. Nevertheless, if a signal x is transmitted over the single antenna at any given time t, the received signal can be expressed by:

$$y(t) = Hx(t) + n(t) \tag{2}$$

where y(t) is the received signal vector and n is the noise at any time instant. In scenario such as the system shown in Figure 1 using M antenna array, the mathematical definition for the received signal vector in Eq. (2) can be give by:

$$\begin{bmatrix} y_1(t) \\ y_2(t) \\ y_3(t) \\ \vdots \\ y_M(t) \end{bmatrix} = \begin{bmatrix} h_{k,1}(t) \\ h_{k,2}(t) \\ h_{k,3}(t) \\ \vdots \\ h_{k,M}(t) \end{bmatrix} x(t) + \begin{bmatrix} n_1(t) \\ n_2(t) \\ n_3(t) \\ \vdots \\ n_M(t) \end{bmatrix} \tag{3}$$

where h_i and n_i are the ith channel gain and noise between transmit antenna and ith receive antenna, and $i = [1, 2, 3, \cdots, M]$.

Assuming that several objects are in the environment, which causes the transmitted signal to be scattered before arriving at the receiver, a Rayleigh fading channel is considered a practical model. The probability density function (PDF) is given by [13]:

$$P_R(x) = \left(\frac{2r}{\Omega}\right) e^{-\frac{x^2}{\Omega}}, \ x \geq 0 \tag{4}$$

where x is the envelope of a sample of electric field (transmitted signal) and Ω denotes multiplication of in phase and quadrature component of electric field. The Rayleigh distribution, which is defined as a cumulative distribution function (CDF) is given by[13]:

$$F_R(x) = 1 - e^{-\frac{x^2}{\Omega}} \tag{5}$$

$$\Omega = 2\sigma^2 = E[x^2] \tag{6}$$

where σ stands for the scale parameter of the distribution. Given that x is the optimum transmitted signal with unit variance in the channel. Thus the received signal can be defined in terms of Eq. (2) given by:

$$y = \sqrt{\frac{E_b}{N_o}} Hx + z \tag{7}$$

where is E_b the receive signal power, N_o is the noise power and z is the additive Gaussian random variable (with zero-mean) that represents the wireless communication noise.

3.1 System Performance Metrics

This subsection presents the performance metrics considered in this paper to evaluate a massive MIMO system.

- Signal to Noise Ratio

Signal to noise ratio (SNR) is one of the metrics to determine the performance of wireless communication system. It can be expressed as the ratio of received signal power E_b to noise power N_o for the ith channel, which is mathematically defined by:

$$SNR_i = |h_i|^2 \times \left(\frac{E_b}{N_o}\right), \quad i = 1, 2, 3 \cdots M \tag{8}$$

Assuming equal channel for the M receive antenna elements, the resultant signal power to noise power ratio is defined by:

$$SNR = \sum_{i=1}^{R}\left(|h_i| \times \frac{E_b}{N_o}\right) \tag{9}$$

In this paper, the intended signal vector x and the vector noise are assumed to be independently and identically distributed complex Gaussian random variables with zero mean and unit variance expressed in decibel (dB). Thus, the SNR is further defined by:

$$SNR = 10\log_{10}\left(\frac{E_b}{N_o}\right) \tag{10}$$

- Capacity

The capacity of a system is another important performance metric to evaluate a wireless system. Expressed in bits/s/Hz, the capacity of the system defines the rate by which data transfer takes place between the wireless communication links. The capacity of wireless system follows the Shannon theorem. The capacity at which signal can be transmitted over the channel by the transmitter is described by this theorem. Therefore, from the Shannon theorem, the system capacity can be defined by:

$$C = \log_2(1 + SNR) \quad \text{in bits/s/Hz} \tag{11}$$

Equation (11) can be further defined in terms of E_b and N_o by:

$$C = \log_2\left(1 + \frac{E_b}{N_o}\right) \tag{12}$$

The BS is equipped with large arrays of M antennas that receive data from users with N single transmit antennas such that M >> N for massive MIMO system [14], [15].

For uplink communication, the BS receives a signal given by:

$$y(t) = \sqrt{p}Hx(t) + n \tag{13}$$

where $x = [x_1, x_2, x_3, \cdots, x_N]^T$ is transmitted vector symbol, x_N is the signal transmitted by the single Nth antenna. The H is the channel gain (matrix) between the M antennas at the BS and the N user antenna. The expression p is the normalized SNR of every user and n is the additive white Gaussian noise (AGWN) with zero mean and variance 1.

Hence, the resultant capacity of the system for uplink scenario considered in this paper is given by [12]:

$$C = \log_2\left(\det\left(I_N + PH^H H\right)\right) \tag{14}$$

Equation (14) is used to determine the system capacity

3.2 Maximal Ratio Combining

Maximizing the output SNR of the signal requires that all the received signals must be considered. That means one signal can be chosen while neglecting others. Therefore, the entire signal must be combined in such a way that the output signal gives all transmitted information. For MRC, weighted bits are assigned to the signal in order to make them strong.

The MRC scheme provides the necessary linear combination of the received signal $y_i(t)$ with weighting coefficient β_i of the *ith* channel (or branch). The overall output signal y(t) of the resulting linear diversity combiner is expressed as:

$$y(t) = \sum_{i=1}^{M}\beta_i y_i(t) = x(t)\sum_{i=1}^{M}\beta_i h_i + \sum_{i=1}^{M}\beta_i n_i \tag{15}$$

Given that a unit power is assumed for x(t), the average SNR for MRC is given by:

$$SNR_{MRC} = \frac{1}{\sigma^2}\left(\frac{\left|\sum_{i=1}^{M}\beta_i h_i\right|^2}{\sum_{i=1}^{R}|\beta_i|^2}\right) \tag{16}$$

The SNR at the output of combiners considering the overall channel matrix is given by:

$$SNR_{MRC} = \frac{E_b}{N_o}\left(\frac{\left|W_{MRC}^T H\right|^2}{\left\|W_{MRC}^T\right\|_2^2}\right) \tag{17}$$

where W_{MRC}^T is the weighting vector and represents the weights. Figure 2 is a block diagram description of MRC technique.

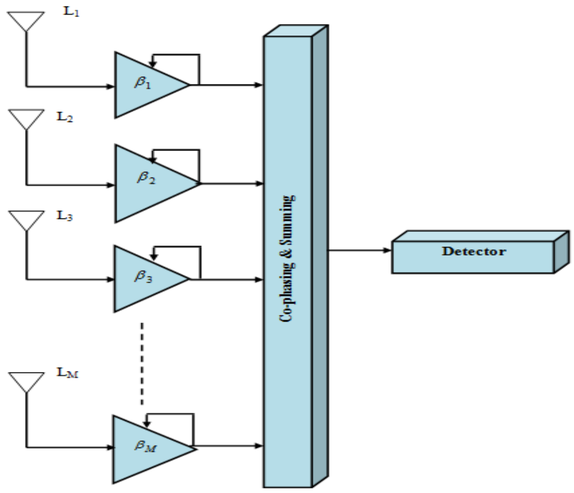

Fig. 2 Block diagram of MRC technique

3.3 Selection Combining

If there are N copies of the same transmitted signal at the receiver, then it is necessary to effectively combine them so as to reliably recover the transmitted data. Assuming an independent fading for each signal, selection combing (SC) diversity scheme will enable the antenna with the highest received signal power to be selected by the receiver and neglects observations from other antennas. Thus, weighted values are assigned to the signals such that weight 1 is allocated to maximum power signal while weight 0 is assigned to others in order to obtain one significant signal at the output. Since each signal exists as a separate sample of the fading process, the signal with the highest SNR is selected for further processing [16]. The mathematical expression for the average of instantaneous SNR for SC is defined by [16]:

$$\mathrm{SNR}_{SC} = E\left\{ \max_{i} \left(|h_i|^2 \right) \right\} \times \frac{E_b}{N_o}, \quad i = 1, 2 \cdots M \tag{18}$$

The block diagram representation of the SC diversity technique is shown in Fig. 3.

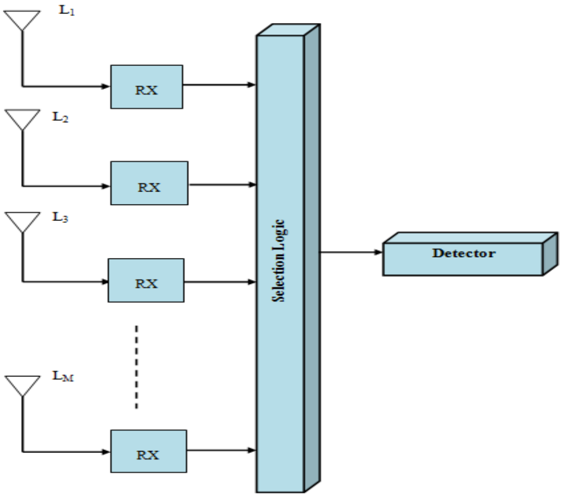

Fig. 3 Block diagram of SC diversity technique

3.4 Equal Gain Combining

There are instances when providing for the variable weighting capability needed for MRC is not convenient. In which case, the branch weights of MRC are all set as 1, however the each branch signals are co-phased to offer EGC. The receiver branches are assigned equal weights that make the signals equally stronger or amplified in this technique [16]. The mathematical model of EGC is given by [16]:

$$\mathrm{SNR}_{EGC} = \left(1 + \frac{\pi}{4}(N-1) \right) |h_i|^2 \times \frac{E_b}{N_o} \tag{19}$$

where SNR_{EGC} is the SNR of EGC.

The block diagram of EGC scheme is shown in Fig. 4.

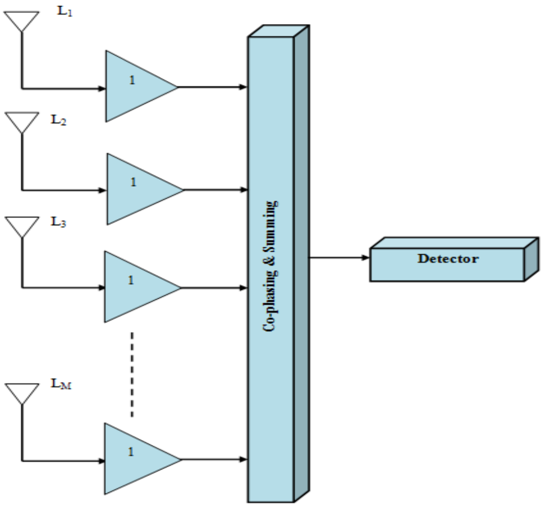

Fig. 4 Block diagram of EGC technique

3.5 Simulation Parameters

The parameters used for simulation study to perform capacity analysis in massive MIMO system are shown in Table 1. Note that though the number of users N = 16 is considered, it is assumed that each user has equipment (UE) with single antenna communicating with M receiver antennas with BS at time.

Table 1 Simulation parameters

Definition	Symbol	Value
No. of receive antennas at BS	M	128, 256, 512
No of users	N	16
Signal to noise ratio (dB)	SNR	1:30

IV. SIMULATION RESULTS

The results of the analysis performed in MATLAB simulation environment is presented in this section. Simulations have been conducted for massive MIMO system wherein multiple receive antennas located at BS communicate with a single transmit antenna at a time among N transmitting antennas from different UEs over Rayleigh fading channel. The number of receive antennas (M) was varied for 128, 256, and 512 in order to evaluate system performance in terms of SNR and capacity for the three space receive diversity schemes: MRC, SC, and EGC. The number of symbol is equal to 10^4.

3.1 Signal to Noise Ratio Performance

This subsection presents the simulation results in terms of SNR for the different number of antenna elements configuration.

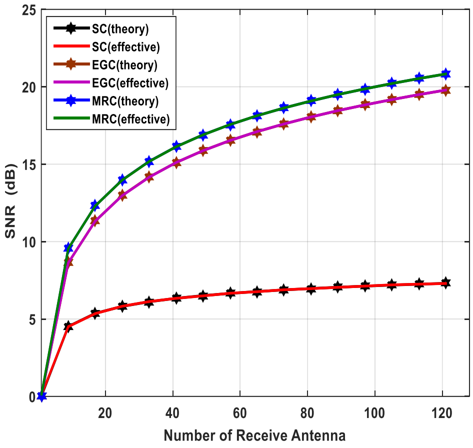

Fig. 5 SNR performance (for M = 1:8:128)

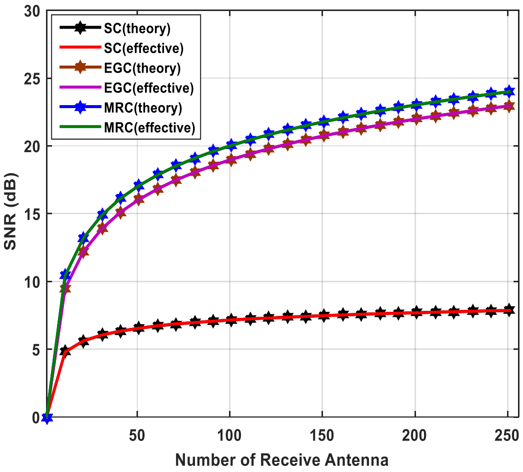

Fig. 6 SNR performance (for M = 1:10:256)

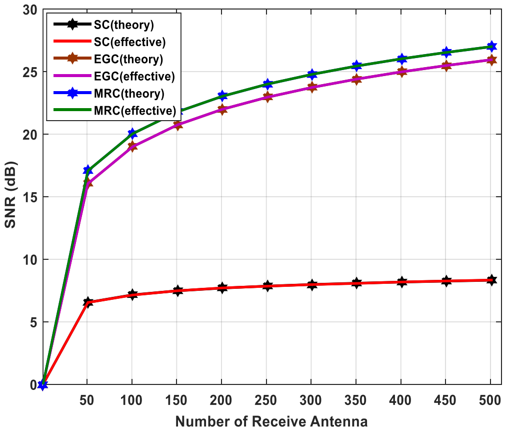

Fig. 7 SNR performance (for M = 1:50:512)

Figures 5, 6, and 7 shows that the system performance is improved for the various receive space diversity schemes as the number of receive antennas at the BS increases. The effective and theory SNR with MRC outperformed that of SC and EGC. Thus for M = 128, SC provided SNR of 7.31 dB whereas EGC and MRC offered SNR of 19.79 dB and 20.83 dB respectively. For M = 256, the achieved SNR with respect to SC, EGC, and MRC was 7.85 dB, 22.95 dB, and 24 dB respectively. Finally, for M = 512, the SNR yielded was 8.34 dB, 25.96 dB, and 27 dB using SC, EGC, and MRC respectively.

Generally, the figures show the SNR performance of the system using various space receive diversity techniques when the number of receive antennas was varied from 1to 128, 1 to 256, and 1to 512. The curves proved that the MRC offers the best performance among the three schemes.

3.2 Capacity Performance

The simulation results for the system performance in terms of capacity considering the various space receive diversity techniques are presented in this subsection. In this scenario, the system capacity in bits/s/Hz is plot against the number of received antennas and comparison made for SC, EGC, and MRC.

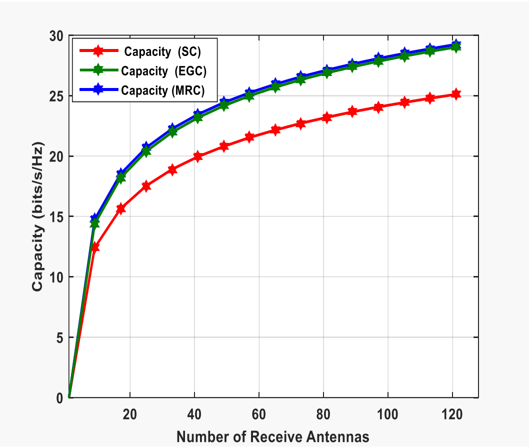

Fig. 8 Capacity performance (for M = 1:8:128)

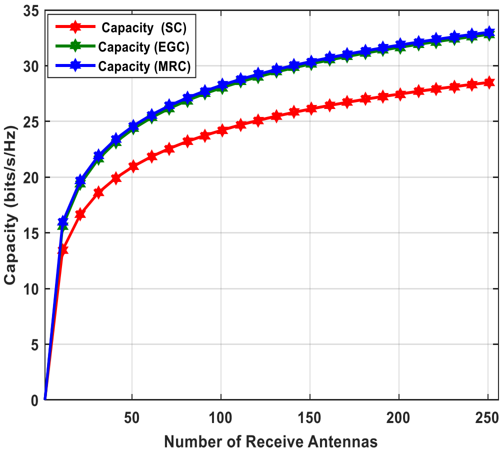

Fig. 9 Capacity performance (for M = 1:10:256)

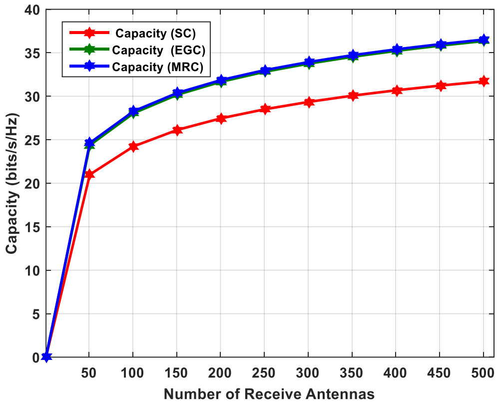

Fig. 10 Capacity performance (for M = 1:50:512)

The simulation curves shown in Figures 8, 9, and 10 are the massive MIMO performance evaluated in terms of its capacity using SC, EGC, and MRC. The curves provide solutions to the system capacity when the number of antennas increases from 128 to 512. With M = 1:8:128 as shown in Figure 8, SC yielded a capacity of 25.1 bits/s/Hz, while EGC and MRC offered capacity of 29.01 bits/s/Hz and 29.23 bits/s/Hz respectively. Also, with M = 1:10:256 as shown in Figure 9, the system capacity with respect to SC, EGC, and MRC was 28.51 bits/s/Hz, 32.82 bits/s/Hz, and 33.02 bits/s/Hz respectively. Lastly, in Figure 10 when M = 1:50:512, the capacity obtained with respect to the various schemes was 31.72 bits/s/Hz using SC, 36.36 bits/s/Hz using EGC, and 36.53 bits/s/Hz using MRC.

Hence, from the results, it can be remarkably said that increasing the number of antennas results in improved massive MIMO capacity. In addition, among the three schemes, the MRC provided the most promising performance for the system capacity and SNR for the simulation carried out in the same time frame.

V. CONCLUSION

This paper has presented a quantitative performance comparison of selection combining (SC), equal gain combining (EGC), and maximal ratio combining (MRC) for massive MIMO system in terms of SNR and capacity over Rayleigh fading channel. The results from the simulation analysis revealed that the system performance is enhanced with increasing number of receive antennas. Also, while the SNR and capacity of the system is improved by the three space receive diversity as the number of receive antennas increases, the MRC proved to provide the best performance among the three techniques. In future study, authors intend to implement optimization technique based intelligent algorithm with MRC in massive MIMO system.

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