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Maximizing the Capacity of Large Scale MIMO Based on Maximal Ratio Combining

Okoye Anulika Joy[1], C.B. Mbachu[2], S.A Akaneme[3], C.A. Nwabueze[4],
[1,2,3,4,] Dept. of Electrical/Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University Uli, Anambra State Nigeria.

Abstract:- Wireless mobile communication system has become an attractive technology and continues to evolve due to increasing demand for high data speed performance. In order to achieve high rate of data and to meet growing demand in mobile communication, large scale multiple antennas system involving the use of hundreds of antenna at the base station is regarded as a promising technology for next generation of wireless communication standard such as fifth generation (5G). However, due to multipath effect in wireless channel, the problem of severe attenuation in transmitted signal arises, which makes it very difficult for the receiver at base station (BS) to determine the optimum transmitted signal and thereby causing system performance metrics such as capacity to degrade. This paper presents maximizing receive capacity in large scale multiple input multiple out (or massive-MIMO) system based on maximal ratio combining (MRC) beamforming. The system is designed to mitigate multipath fading effect to improve system performance. The mathematic model of massive multiple antennas system channel was derived and maximum ratio combining technique was formulated. The entire system was modeled in MATLAB. Simulation results obtaining considering wireless communication over Rayleigh fading with varying number of base station antennas (M) using MRC indicated that system capacity for M = 128, 150, 200, 256, and 512 resulted in capacity of 29.53 bit/s/Hz, 30.36 bit/s/Hz, 31.85 bit/s/Hz, 33.12 bit/s/Hz, and 36.64 bit/s/Hz. Further simulations were conducted to compare the performance of MRC with selective combining (SC) and equal gain combining (EGC). The results of the comparison indicated that MRC outperformed SC and EGC. Therefore, the results of the developed system studied using typical parameters of 5G and implementing MRC to achieve improved performance in terms of capacity show it potential.

Keywords:- *Large Scale MIMO, Maximum Ratio Combining, System Capacity, Wireless Communications.*

I. INTRODUCTION

With the wireless data traffic around the world dramatically increasing, existing wireless communication systems have witnessed significant demands. This situation will overwhelm existing infrastructure of 3Gpp and 4G networks. Hence, using a technology that involves the overlaying of small BSs within the main network in terms of coverage demands can be a promising strategy to achieve significant expansion and capacity of wireless network. The limited availability of spectrum has made the attention of experts in telecommunication to focus in the direction of millimeter wave (mm-wave) frequencies that require miniature radiating antenna. This reduction of the size of antenna element absolutely fits the massive MIMO requirement and thereby making the use of these large-scale arrays a potential technology (Han et al., 2015; Khwandah et al., 2021). Also, an improved performance and a better signal to interference-plus-noise ratio (SINR) can be obtained by increasing the number of antenna elements. In conventional Multiple Input Multiple Output (MIMO) systems, maximum of 8 antenna arrays are used at both the transmitting and receiving sides (that is 8×8 MIMO system). Conversely, in large-scale MIMO system (massive MIMO) and based on the prototype being implemented, for fifth generation (5G) network, the base station (BS) can take up to 256 antennas and user equipment (UE) up to 32 (Khwandah et al., 2021). Significant throughput (or spectral efficiency) and improvements in coverage in mobile networks can be realised. Additionally, combining energy in required directions using multiple antenna elements can help to overcome higher path loss due to high frequencies. This results in the introduction of beamforming schemes into MIMO and thereby leading to the concentration of radio energy in smaller angular sectors, which brings about significant improvement in spectral efficiency. Thus, massive MIMO introduction in wireless communication system has brought about the emergence of a new promising technique.

In the next generation of wireless system such as 5G, it is expected that data rates for a user will explosively increase (Alquhaif et al., 2019). The 5G wireless network uses massive MIMO as its exciting area that promises significant gains, which provide the ability for more users to be accommodated at higher data rates with improved reliability even as less power is consumed. The concept of 5G massive MIMO is that equipping the base station with several more antennas can serve far more UEs or terminals. This way, the technology is usually designed to serve multiple users (MU) resulting in a system called MU-massive MIMO.

Initially, MU-MIMO techniques were implemented such that number of BS antennas was equal to the number of UEs or mobile stations (MSs) (Larson et al., 2014), and as such the technology was non-scalable (Amadori & Masouros, 2015). The introduction of massive MIMO has shown that very large antenna elements at BS can provide significant spectral efficiency benefits. Antenna arrays in massive MIMO can take different arrangements and shapes such as cylindrical or uniform linear arrays (ULA), and are rather characterised by small active elements (Larson et al., 2014).

Generally, massive MIMO offers to be novel approaches to practically employ the concepts of MU-MIMO, where non-

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cooperative mobile station or single UEs are served at the same time by a BS with a very large number of antennas. When the number of antennas at the BS is much larger than UEs, an optimal low complexity linear signal processing can be achieved (Alshammari, 2017). Using massive MIMO has proven to provide significant improvements in the radiated energy and channel capacity. Also, much higher capacity and speeds are guaranteed by 5G wireless communication systems under scarce spectrum and constrain power compared with the current systems (4G and other lower standards) (Tehrani et al., 2014).

Considering that fact that performance of any wireless system can be improved in terms of capacity and energy efficiency (Alshammari, 2017), this paper aims at maximising the capacity of large scale MIMO.

II. LARGE SCALE MULTIPLE ANTENNAS TECHNOLOGY

The general concept of large scale multiple antennas system usually called massive-MIMO, is described as a physical-layer technology, which provides each BS with a large number of antennas that has potential to spatially multiplex several UEs in order that communicating with them on the same time-frequency resource is possible. It is possible to improve the spectral efficiency per cell by orders-of magnitude better than conventional wireless mobile networks by dealing with interference and signal attenuation by the means of spatial signal processing with methods like transmit precoding and receive combining (Borges et al., 2021). In effect, massive-MIMO is an improved or extended version of the Space-Division Multiple Access (SDMA) in which spatial multiplexing is pushed to an extreme level (Ngo, 2019).

The most important advantages of large scale MIMO (or massive-MIMO) systems are (Borges et al., 2021):
1) It provides huge spectral efficiency.
2) It guarantees high energy efficiency.
3) It offers better link reliability.
4) It makes the signal processing complexity to be low.
5) It offers favourable propagation.
6) It ensures hardening of channel.

All the benefits of classical MU-MIMO are inherited by massive-MIMO. That is, with M number of BS antennas and K number of single-antenna users, it is possible to achieve an M order diversity and a multiplexing gain of min (M,K). Also, it is possible to achieve large spectral efficiency and incredibly high link reliability with simple linear precoding technique.

When MIMO arrays are made larger, many asymptotic limits of random matrix theory are approximated by the law of numbers (Chen & Bjornson, 2018). Each antenna is expected to be contained in low-cost module with an amplifier of low power and simple processing capacity. Several products can be employed in designing the system as procedures that were before random appears to be deterministic now (Borges et al., 2021). For instance, the channel matrix singular values distribution that tends to a deterministic function (Ngo & Larsson, 2017). An additional example is the fact that very large or very high matrices have a tendency to be superbly conditioned (Borges et al., 2021). Furthermore, certain matrix operations like inversions can be performed fast by employing the methods of series expansion when dimensions are large. Also, linear precoding techniques such maximum ratio combining (MRC) for uplink and maximum ratio transmission (MRT) for downlink operations is optimal in the limit of an infinite number of BS antennas (Borges et al., 2021).

In this paper, the scheme is to provide near optimal capacity for massive MIMO system in uplink communication considering receive antenna selection with maximal ratio combining (MRC). In the developed scheme, the number of receive antennas are selected to determine the capacity of the massive MIMO in terms of bit/sec/Hz of data rate by increasing the number of receive antennas (at the BS).

III. SYSTEM DESIGN AND MODELLING

This section presents the large scale system model. The system is an arrangement consisting of multiple antennas at the base station and mobile terminal. Now consider a massive large scale antenna system with a receive diversity system and having large receive antennas, M and a user with a single transmit antenna N system shown in Figure 1. In order to simplify the design, the following assumptions are made:
1. Transmitted signal is optimum with binary phase shifting modulation.
2. The antennas at the receive end share the same time and frequency resources.
3. A single antenna is serving large scale terminals or antennas at the receive end at the same time (that is massive MIMO system with receive diversity).
4. The transmitted signal has unit power.
5. The channel is assumed to be perfect.

It should be noted that in this work that the base station is considered the receiving end with massive antenna arrays assuming a scenario when a user is making call from its mobile terminal. The entire arrangement is a single cell system model representing a large scale multiple antenna system with beamforming techniques.

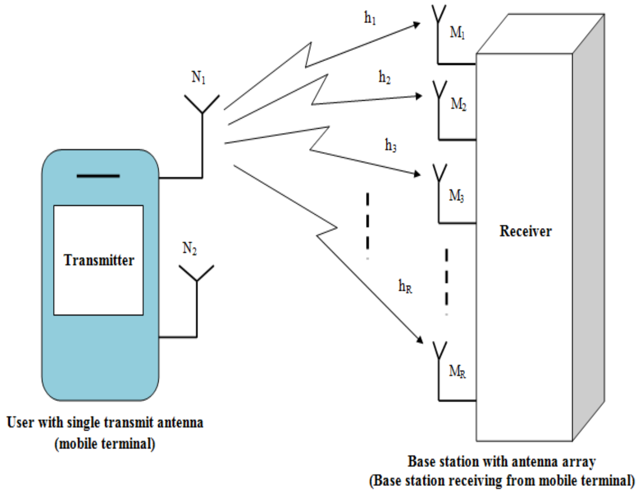

Fig 1: System model

A. Capacity Derivation of a Massive MIMO System

Another metric for quantifying the performance of a wireless system is based on capacity of the system that defines the rate of data transfer in bits/second/hertz (bits/s/Hz) through the channel. 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 theorem. Thus from the Shannon theorem, the system capacity can be defined by:

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

It can be further expressed in terms of E_b and N_o as:

$$C = \log_2\left(1+\frac{E_b}{N_o}\right) \quad (2)$$

In massive multiple input multiple output (MIMO) system, the base station (BS) is equipped with large arrays of M antennas that receive data from users with N single transmit antennas such that M >> N (Gupta and Jha, 2015; Agyapong et al., 2014).

For an uplink scenario, the BS receives:

$$y(t) = \sqrt{P}Hx(t) + n \quad (3)$$

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 N^{th} 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.

Thus the overall capacity of the channel model for the uplink scenario considered in this work can be expressed by Judal and Maradia (2019):

$$C = \log_2\left(\det\left(I_N + PH^H H\right)\right) \quad (4)$$

B. Maximal Ratio Combining

In this section MRC being the beamforming technique developed in this work to provide the necessary linear combination of the received signal $y_i(t)$ with weighting coefficient β_i of the i^{th} channel (or branch). The overall output signal y(t) of the resulting linear diversity combiner is given by:

$$y(t) = \sum_{i=1}^{R}\beta_i y_i(t) = x(t)\sum_{i=1}^{R}\beta_i h_i + \sum_{i=1}^{R}\beta_i n_i \quad (5)$$

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

$$SNR_{MRC} = \frac{1}{\sigma^2}\left(\frac{\left|\sum_{i=1}^{R}\beta_i h_i\right|^2}{\sum_{i=1}^{R}|\beta_i|^2}\right) \quad (6)$$

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

$$SNR_{MRC} = \frac{E_b}{N_o}\left(\frac{\left|W_{MRC}^T H\right|^2}{\left\|W_{MRC}^T\right\|_2^2}\right) \quad (7)$$

where W_{MRC}^T is the weighting vector and represents the weights. The structure of the MRC scheme is shown in Figure 2 in which weighted bits are allocated to the signal so as to make all the signals strong, which is done to improve the faded signals. Looking at Equation (3.16), it is obvious that the SNR largely depends on β_i. Thus, the optimal solution is the weighting vector that maximizes SNR_{MRC}.

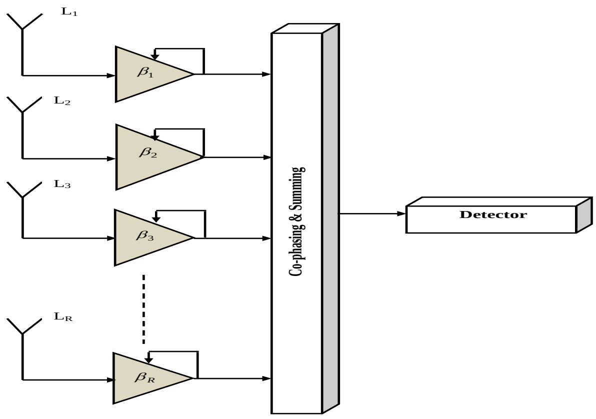

Fig 2: Block diagram of MRC technique

C. Simulation Parameters

In this section, the parameters used in Judal and Maradia (2019) for 5G network in terms of uplink scenario, where data is transmitted from a single antenna N of each user to a BS with massive M antennas are modified by using SNR of 35 dB rather than 10 dB for the simulation analysis of the proposed massive multiple antenna system in this work. The entire simulation studies to evaluate the system will be conducted in MATLAB environment using developed codes for the system that were created as MATLAB extension file (m-file). The parameters are listed in Table 1.

Table 1: Simulation parameters in massive MIMO for 5G system

Description	Parameters
Number of receive antennas at BS (M)	128, 150, 200, 256, 512
No of users N	16 (only a single N^{th} antenna transmits at a time)
E_b/N_o	1:35 (in dB)
Number of bits	10^4
Modulation	BPSK
Channel	Rayleigh

IV. SIMULATION RESULTS AND ANALYSIS

The results of the simulations carried out in MATLAB environment are presented in this chapter. Simulations were considered for massive multiple antennas at the base station serving as receive antennas communication with a single transmit antenna at a time among N transmitting antennas from mobile equipment users. Hence, simulation is conducted using space receive diversity scheme based maximum ratio combining (MRC) for M number of based station antennas with array of 128, 150, 200, 256, and 512 to determine the performance of massive MIMO system in terms of system capacity (bits/s/Hz) in Rayleigh fading channel. Also, numerical analyses are performed for the system capacity against M number of received base station antennas. In order to validate the effectiveness of the MRC technique, simulations were conducted to quantitatively compare it with other schemes such as selection combining (SC) and equal gain combining (EGC). Generally, the simulations are performed based on increasing number of receive antennas so as to achieve near optimal performance in massive multiple antenna system by assuming optimum transmitted signal of 10^4 bits with BPSK modulation scheme and signal to noise ratio of E_b/N_o = 35 dB for digital communication.

A. Space Receive Diversity Performance with MRC for Capacity Improvement

This section presents the simulation results of the space diversity receive capacity performance of the system in bits/s/Hz using with MRC. The graphics of the system capacity are presented in Figures 3 to 7 for increasing number of receive antennas from 128 to 512. The numerical performances of the simulation plots are presented Table 2.

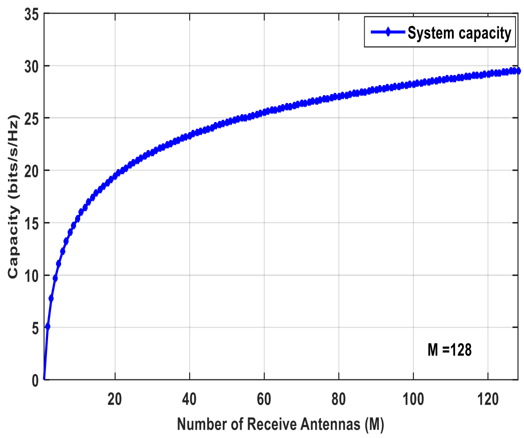

Fig 3: Capacity improvement with maximum ratio combining (for M = 1:1:128)

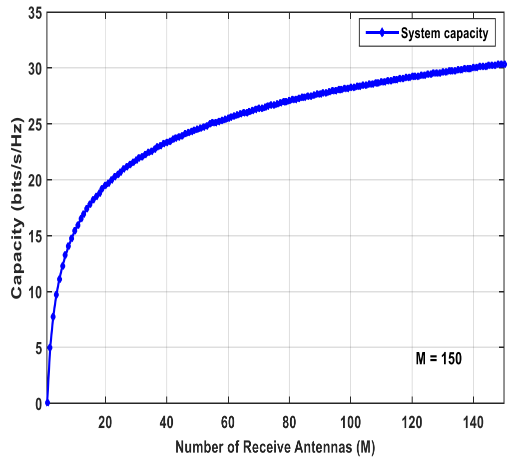

Fig 4: Capacity improvement with maximum ratio combining (for M = 1:1:150)

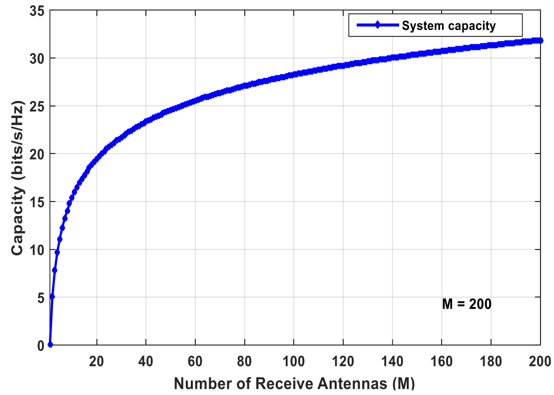

Fig 5: Capacity improvement with maximum ratio combining (for M = 1:1:200)

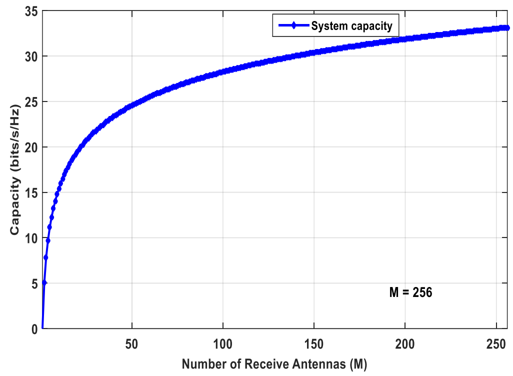

Fig 6: Capacity improvement with maximum ratio combining (for M = 1:1:256)

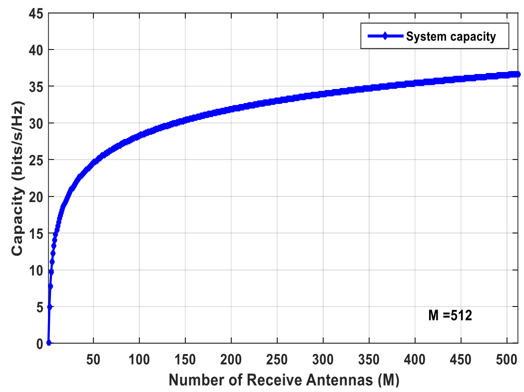

Fig 7: Capacity improvement with maximum ratio combining (for M = 1:1:512)

Table 2: System capacity improvement with MRC

Number of Receive Antennas (M)	Capacity (bits/s/Hz)
128	29.53
150	30.36
200	31.85
256	33.12
512	36.64

With the number of bits or symbol equal to 10^4 and the system capacity performance improves as the number of receive antennas increases. The numerical performance analysis in Table 2 shows that the capacity of the system was

29.53 bits/s/Hz when M = 128. As the number of receive antennas M increases to 150, 200, 256, and 512,the system achieved capacity increases to 30.36 bits/s/Hz, 31.85 bits/s/Hz, 33.12 bits/s/Hz, and 36.64 bits/s/Hz respectively. Thus, it can be said that the capacity of space receive diversity for massive multiple antenna system can be increased by increasing the number of receive antennas at the base station.

B. Performance Comparison with Different Technique for Capacity Improvement

The results of the capacity improvement of system using different techniques are presented in this section. The capacities in bits/s/Hz of the various select receive antennas schemes are examined when M is considered from 1 to 128 up to 1 to 512 antennas respectively. The simulation plots for the various cases of increasing receive antennas are shown in Figures 8 to 12 and the numerical analysis of each plot is presented in Table 3.

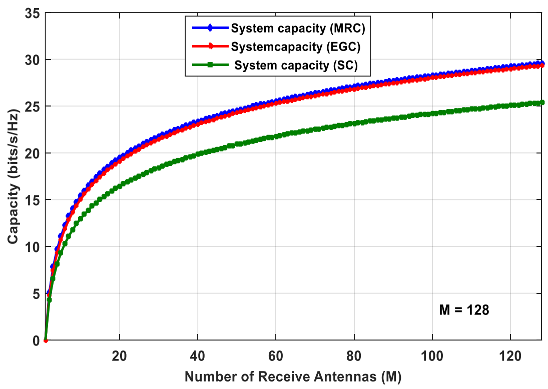

Fig 8: Performance comparison of capacity improvement (M = 1:1:128)

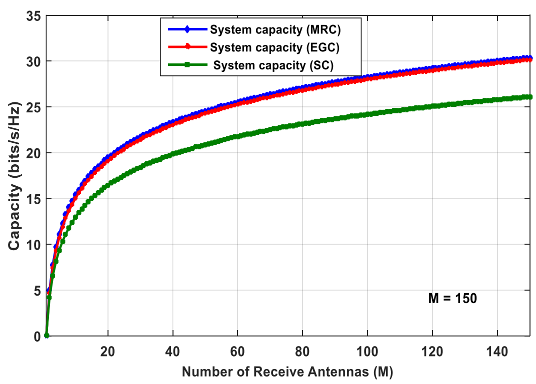

Fig 9: Performance comparison of capacity improvement (M = 1:1:150)

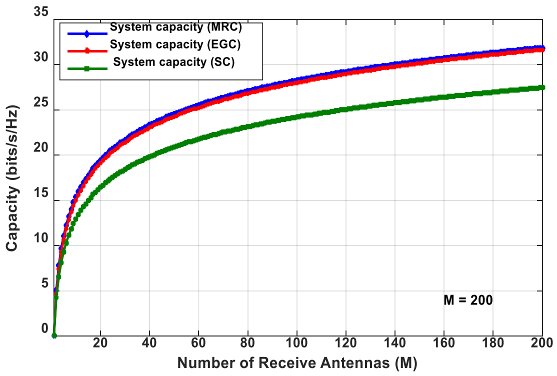

Fig 10: Performance comparison of capacity improvement (M = 1:1:200)

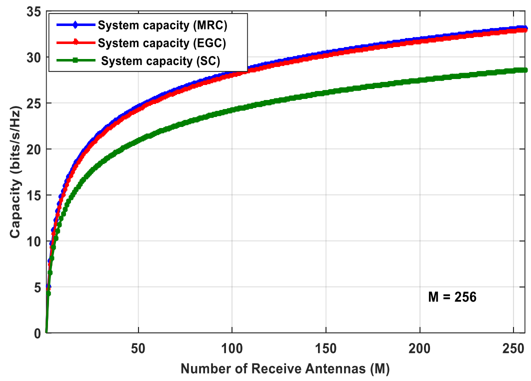

Fig 11: Performance comparison of capacity improvement (M = 1:1:256)

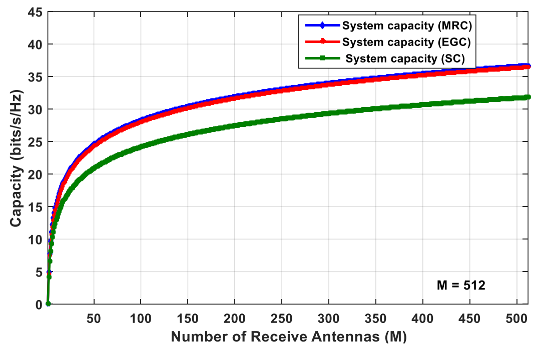

Fig 12: Performance comparison of capacity improvement (M = 1:1:512)

Table 3: Capacity performance improvement with different receive antenna select techniques

Number of Receive Antennas (M)	**Capacity (bits/s/Hz)**		
	MRC	**EGC**	**SC**
128	29.53	29.31	25.37
150	30.36	30.15	26.10
200	31.85	31.65	27.47
256	33.12	32.93	28.60
512	36.64	36.47	31.82

Looking at Table 3, the numerical performance analysis of capacity improvement of the massive multiple antenna based on receive diversity techniques considering receive antenna selection to achieve near optimal performance shows that as the number of receive antenna (M) at the base station increases, the achieved capacity increases. For instance, when M = 128, the capacity of the system was 29.53 bits/s/Hz, 29.31 bits/s/Hz, and 25.37 bits/s/Hz and further increased to 36.64 bits/s/Hz, 36.47 bits/s/Hz , and 31.82 bits/s/Hz with respect to MRC, EGC, and SC respectively. Another obvious observation is the fact the MRC scheme outperformed EGC (though slightly) but largely for SC. Thus, the table shows that better achieved capacity of system was provided by the MRC.

V. CONCLUSION

This scenario is an uplink communication in which a mobile equipment transmits. The performance analyses of simulation results for the proposed system have been presented in terms of system capacity in terms of bits/s/Hz against the number of large receive antennas (M) at the base station. The simulation results showed that based on receive

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antenna selection, that increase in the number of base station antenna offered improved performance of the system in terms of system capacity. Furthermore, the performance of system was analysed by addition simulation conducted using other space receive diversity techniques such as equal gain combining (EGC) and selection combining (SC) such that comparison plots of the developed maximal ratio combining (MRC) with EGC and SC were also presented considering the system capacity. Generally, from the results obtained, it is revealed that by selecting receive antennas at base station in terms of increasing the number of antenna elements improves the receive diversity of massive MIMO system, which leads to near optimal performance.

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