Signal To Noise Ratio Improvement in Massive MIMO Uplink System Based on Receive Antenna Selection

OKOYE ANULIKA JOY[1], C.B. MBACHU[2], C.A. NWABUEZE[3]
[1, 2, 3] Dept. of Electrical/Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University Uli, Anambra State Nigeria.

Abstract- There is no doubt that in wireless communication, performance and capacity of the system has been improved in the past few decades as a result of advances in technology in this area. However, meeting up with stringent demands of future wireless networks requires the development of techniques that will solve the anticipated rise in data traffic of diverse mobile networks to ensure effective transmission capacity. Some approaches have been presented by researchers to improve transmission capacity. One of such methods is by increasing spectral efficiency or employing more bandwidth, but this approach has become less attractive because spectrum is constrained being a natural resource, which must be shared by multiple communication services.

I. INTRODUCTION

There is no doubt that in wireless communication, performance and capacity of the system has been improved in the past few decades as a result of advances in technology in this area. However, meeting up with stringent demands of future wireless networks requires the development of techniques that will solve the anticipated rise in data traffic of diverse mobile networks to ensure effective transmission capacity. Some approaches have been presented by researchers to improve transmission capacity. One of such methods is by increasing spectral efficiency or employing more bandwidth, but this approach has become less attractive because spectrum is constrained being a natural resources, which must be shared by multiple communication services. Therefore, reallocation of portions of the spectrum allocated for other services must be done for mobile communications to augment frequency spectrum of operations. This strategy can be carried out at an incredibly limited degree that cannot meet next generation of wireless mobile data traffic demand (Alshammari, 2017). Besides, spectrum being one of the highly contested resources is very expensive for mobile wireless communication operators. Also, to increase data rates in certain areas, aggressive spectrum reuse techniques such as small cells have been used. Nevertheless, the small cell strategy is less effective because of high mobility users and wide area network (Ngo et al., 2014). Hence, a massive MIMO technology is projected as a promising technology that will satisfy demand for data traffic improvement in mobile network.

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).

Large-scale base station (BS) using hundreds of transmit antennas often called massive MIMO, is projected to be among the several other technologies that will be used in next generation of wireless networks such as the 5G. Nevertheless, there are several problems such as multiuser interference, capacity, energy efficiency, complexity and others that need to be addressed before 5G networks will be finalized. Therefore, many recent studies are designed for this purpose. Transmission capacity performance, which includes channel capacity amongst others such as Bit Error Rate (BER) and Signal to Noise Ratio (SNR) and spectral efficiency, is one of the most essential performance measures of any wireless network. However, there is insufficient average data rate (bit/sec/Hz) to each user given the limited resource a base station can allocate (Wu et al., 2021). Also much consideration has not been given to receive diversity in which a user for instance making call is now transmitting to base station with large scale antennas. In this case, the base station serves as the receiver while the user terminal serves as transmitter. However, despite the use of large scale antenna, the problem of severe attenuation in transmitted signal due multipath effect that makes it very difficult for the receive antennas at BS has not been given considerable attention. Therefore, it is important to select a given number of receive antennas for near optimal capacity performance and increasing the number of receive antennas can be affective. With many technique already developed by previous studies in massive MIMO, reducing the complexity and computation time is largely still common among the existing systems and have mainly focused on transmit antenna selection considering the base station.

In this paper, a technique based on maximum ratio combining with multiple receive antenna selection (RAS) is proposed to improve signal to noise ratio (SNR) performance of massive-MIMO system. This approach offers reduce wireless network complexity and satisfy the need for higher data rates.

II. 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 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.

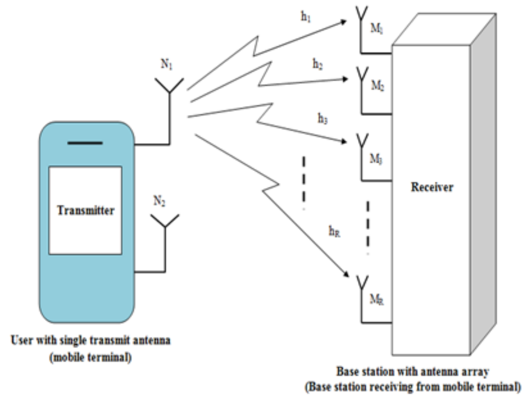

Figure 1: System model

Let a wireless mobile network with Rayleigh channel consisting of M_R of antenna array at the base station receiving from user equipment with a single transmit antenna M. The matrix of a MIMO channel H between transmitter and receiver due to the space diversity communication of the multiple antennas between both ends is given by:

$$H = [h_1 \quad h_2 \quad h_3 \quad \cdots \quad h_R]^T \tag{1}$$

where H represents the channel (gain) matrix, h_R denotes the independent Rayleigh fading channels. However, if a signal x is transmitted over the single transmitted antenna at any time instant t, the received signal vector can be represented by:

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

where y is the received signal vector and n is noise matrix.

In the case of a system such as the one considered in this work that is exploiting M_R antennas at the receiver ($M_R > 1$), an expression for the received signal vector in Equation (2) can be rewritten as:

$$\begin{bmatrix} y_1(t) \\ y_2(t) \\ y_3(t) \\ \vdots \\ y_R(t) \end{bmatrix} = \begin{bmatrix} h_1(t) \\ h_2(t) \\ h_3(t) \\ \vdots \\ h_R(t) \end{bmatrix} x(t) + \begin{bmatrix} n_1(t) \\ n_2(t) \\ n_3(t) \\ \vdots \\ n_R(t) \end{bmatrix} \tag{3}$$

where h_i and n_i are the i^{th} channel gain and noise between transmit antenna and i^{th} receive antenna, and $i = [1, 2, 3, \cdots, R]$.

When there are several objects in the environment that scatter the transmitted signal prior to its arriving at the receiver, the Rayleigh fading channel is considered a practical model. For Rayleigh channel, the probability density function (PDF) is given by Hendre (2015):

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

where x denotes the envelope of a sample of electric field (transmitted signal) and Ω is stands for multiplication of in phase and quadrature component of electric field. The Rayleigh distribution, which is expressed as a cumulative distribution function (CDF) is given by Handre (2015):

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

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

where σ is the scale parameter of the distribution.
Let x represents the optimum transmitted signal with unit variance in the channel. Thus the received signal can be expressed in terms of (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.

A. Signal to Noise Ratio Equation

One of the metric to determine the performance of wireless communication system is signal to noise ratio (SNR). It is the ratio of receive signal power to noise power for the i^{th} channel, which is expressed as:

$$SNR_i = |h_i|^2 \times \frac{E_b}{N_o}, i = 1, 2, \cdots R \tag{8}$$

Assuming equal channel for the R receives antennas, the resultant signal power to noise power ratio is given 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 taken to be independently and identically distributed complex Gaussian random variables with zero mean and unit variance. Expressed in decibel (dB), the SNR is further given by:

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

B. Maximal Ratio Combining

In this section MRC being the beamforming technique developed in this paper to give 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:

$$y(t) = \sum_{i=1}^{R}\beta_i y_i(t) = x(t)\sum_{i=1}^{R}\beta_i h_i + \sum_{i=1}^{R}\beta_i n_i \tag{11}$$

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

$$SNR_{MRC} = \frac{1}{\sigma^2}\left(\frac{\left|\sum_{i=1}^{R}\beta_i h_i\right|^2}{\sum_{i=1}^{R}|\beta_i|^2}\right) \tag{12}$$

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

$$SNR_{MRC} = \frac{E_b}{N_o}\left(\frac{\left|W_{MRC}^T H\right|^2}{\left\|W_{MRC}^T\right\|_2^2}\right) \tag{13}$$

where W_{MRC}^T is the weighting vector and represents the weights. The structure of the MRC scheme is shown in Fig. 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 Eq (11), it is obvious that the SNR largely depends on β_i. Therefore, the optimal solution is the weighting vector that maximizes SNR_{MRC}.

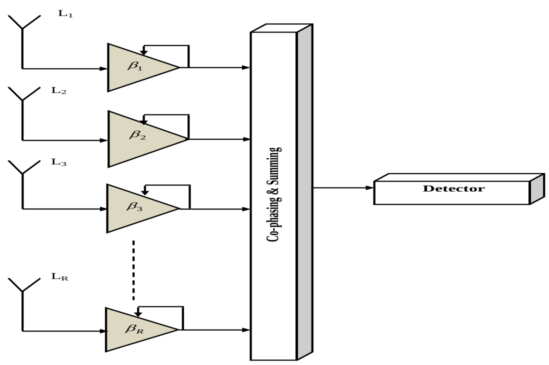

Figure 2: Block diagram of MRC technique

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 paper. 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: Typical 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

III. SIMULATION RESULTS AND DISCUSSION

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 on 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 signal to noise ratio (SNR) in dB. Also, numerical analyses are performed for the graphical plots of SNR 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 SNR Improvement

The first simulation in this case involve the performance of MRC in massive multiple antenna system in Rayleigh fading channel is examined in terms of SNR performance against 1 to 128 receive antennas at the base station as shown in Fig. 3. Furthermore, simulations were conducted to investigate the effect of increasing the receive antennas from 150 up to 512 as shown in Fig. 4 to 7. The numerical analyses of the graphs are presented in Table 2.

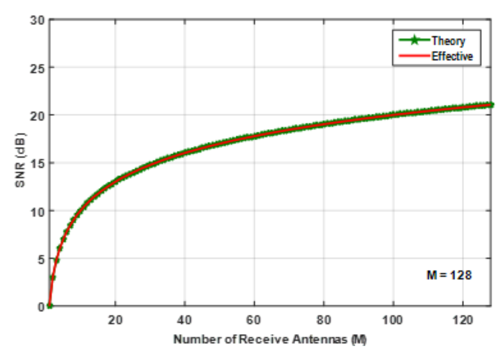

Fig. 3: SNR improvement with maximum ratio combining (for M = 1:1:128)

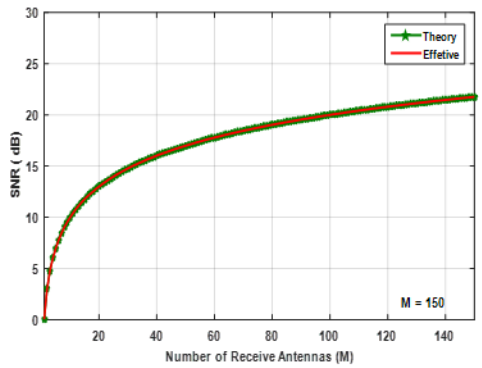

Fig. 4: SNR improvement with maximum ratio combining (for M = 1:1:150)

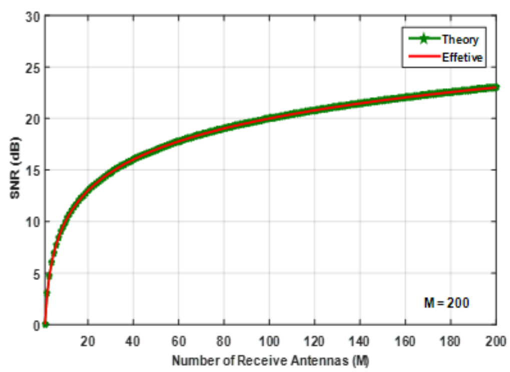

Fig. 5: SNR improvement with maximum ratio combining (for M = 1:1:200)

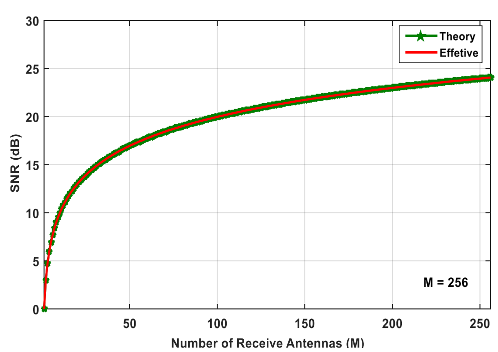

Fig. 6: SNR improvement with maximum ratio combining (for M = 1:1:256)

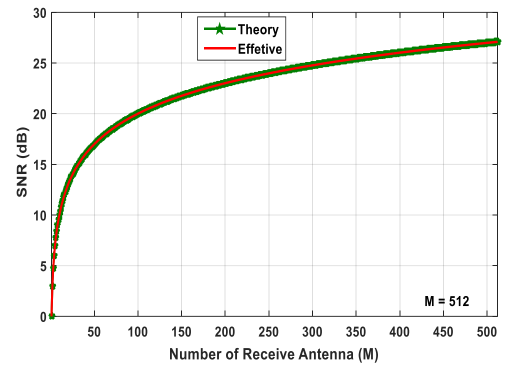

Fig.7: SNR improvement with maximum ratio combining (for M = 1:1:512)

Table 2: SNR improvement with MRC

Number of Receive Antennas (M)	SNR (dB)	
	Effective	Theory
128	21.07	21.07
150	21.76	21.75
200	23.01	23.02
256	24.09	24.08
512	27.10	27.09

The simulation plots in Figures 4.1 to 4.5 show that with the number of bits or symbol equal to 10^4, the SNR performance of the system improves as the number of receive antennas increases. The numerical performance analysis shown in Table 4.1 reveals that when the number of receive antennas M at the base station was 128, the SNR achieved was 21.07 dB and this value increases steadily to 21.76 dB for M = 150, 23.01 dB for M = 200, 24.09 dB for M = 256, and 27.10 dB at M = 512 respectively. The achieve simulation (effective) values were the same as theoretical values in all cases.

B. Performance Comparison with different Techniques for SNR Improvement

The performance comparison of simulation results of SNR improvement with different receive antenna selection techniques for space received diversity with the designed MRC presented in this work. Hence, with MRC technique two other receive selection schemes: selection combining (SC) and equal gain combining (EGC). Simulations were conducted by increasing the number of antennas from 128 to 512 as shown in Fig. 8 to 12. Table 3 shows the numerical performance values of SNR for the various plots with respect to MRC, SC, and EGC.

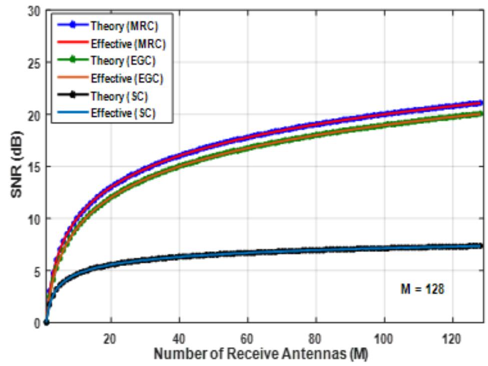

Fig.8 Performance comparison of SNR improvement (M = 1:1:128)

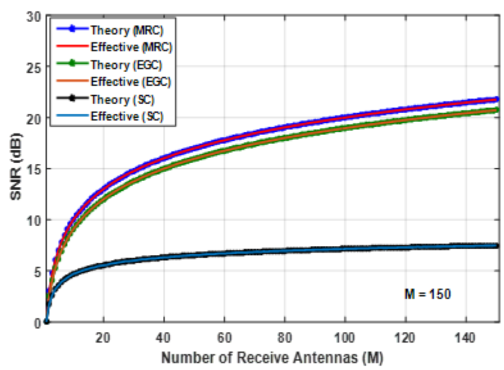

Fig. 9: Performance comparison of SNR improvement (M = 1:1:150)

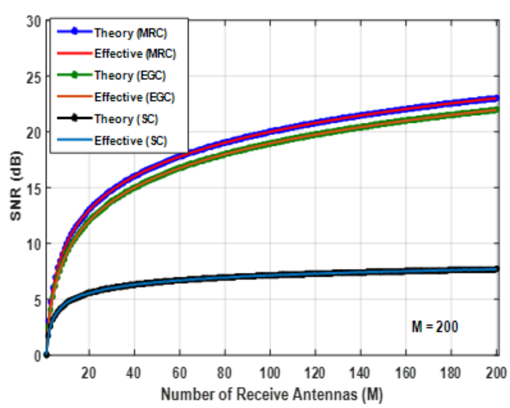

Fig.10: Performance comparison of SNR improvement (M = 1:1:200)

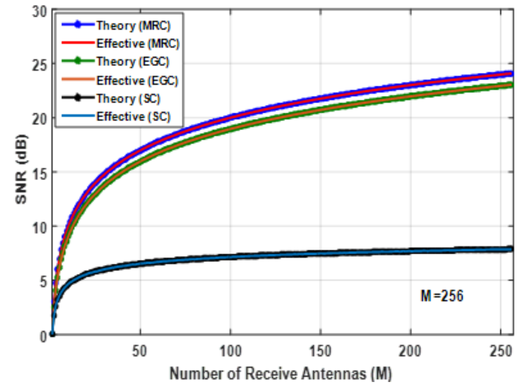

Fig. 11: Performance comparison of SNR improvement (M = 1:1:256)

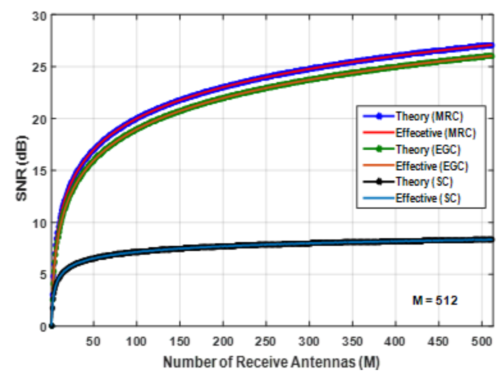

Fig. 12: Performance comparison of SNR improvement (M = 1:1:512)

Table 3: SNR gain performance improvement with different receive antenna select techniques

Number of Receive Antennas (M)	SNR (dB)					
	MRC		EGC		SC	
	Effective	Theory	Effective	Theory	Effective	Theory
128	21.07	21.07	20.04	20.04	7.349	7.347
150	21.76	21.75	20.72	20.71	7.469	7.468
200	23.01	23.02	21.97	21.95	7.681	7.681
256	24.09	24.08	23.04	23.03	7.877	7.881
512	27.10	27.09	26.05	26.03	8.328	8.325

From Table 3, it is obvious that as the number of receive antennas M increases, the SNR gain performance of the system improves for the three select receive antenna techniques compared. In all the cases, the MRC outperformed the other schemes with SC yielding the least improvement in SNR gain. For instance, when M = 150, the effective SNR = 21.76 dB, 20.72 dB, and 7.469 dB for MRC, EGC, and SC respectively. The simulated results are approximately the same with the theoretical results in all cases.

IV. CONCLUSION

This paper has presented signal to noise ratio (SNR) in massive MIMO uplink system based on receive antenna selection maximal ratio using combining (MRC) beamforming. The system was implemented using MRC considering transmission over Rayleigh fading channel to compressed the effect of multipath and select the maximum combining technique for large scale multiple antenna system. The simulations were conducted and the results showed that by increasing the number of receive antennas M, improves the performance of wireless communication system. Analysis of the system in terms of 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, showed that for M = 128, 150, 200, 256, and 512, the SNR improvements in dB achieved were: 21.07, 21.76, 23.01, 24.09, and 27.10. Performance comparison was conducted for MRC and other receive diversity technique and the results considering both performance metrics indicated that MRC provided better improvement compared with the other two techniques (SC and EGC) for a massive MIMO examined in this paper. Generally, the results from the simulations have indicated that optimizing the number of receive antenna based on selection by changing the number of antennas at base station can provide improved SNR. Therefore, the proposed system studied using typical parameters of 5G reveal its capability in improving the SNR of wireless communication system.

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