



Enhancing the Performance of Non-Orthogonal Network for 5G Application

Ugwu, Chekwube Romanus¹; Achebe, P.N.²; Nwabueze, C.A.²; Muoghalu, C.N.²

¹Federal Polytechnic Oko, Nigeria

²Chukwuemeka Odumegwu Ojukwu University, Nigeria

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*Corresponding Author: Achebe, P.N.

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Abstract

Original Research Article

Non-Orthogonal Multiple Access (NOMA) is considered one of the promising radio access technologies that support 5G because it reduces latency and increases system’s spectral efficiency. This work presents performance enhancement of non-orthogonal multiple access (NOMA) network for 5G network application. A model for multiuser NOMA system was developed. With the developed model, downlink communication between a Base Station (BS) and 3 users located at different locations tagged far, mid, and near was simulated in MATLAB environment. The system performance was evaluated with respect to Bit Error Rate (BER), outage probability, and achievable sum rate against Signal to Noise Ratio (SNR) in dB, including Energy Efficiency (EE) against Spectral Efficiency (SE). When the users (UE-1, UE-2, and UE-3) were located at distances 100, 60, and 40 m from the BS, the BER simulated output waveforms of the system revealed that the nearest user (with user equipment, UE-3) had the best quality of signal reception in terms of BER with values: 0.00022 when SNR was 70 dB, 0.000021 when was 80 dB, and 0.0000019 when SNR was 90 dB while the farthest and mid user (UE-1 and UE-2) had BER of (0.00056, 0.000083, and 0.0000095) and (0.00042, 0.000038, and 0.0000038) according to order of the SNR, respectively. Generally, from the analysis, the user (UE-1) achieved the least BER in all cases and it is considered the weakest users. Also, user (UE-3) achieved the best BER and it was regarded as the strongest user.

Keywords: Multiple access, Bit error rate, NOMA, Spectral efficiency, 5G network.

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1. INTRODUCTION

The basic principle of NOMA is that multiple users are served simultaneously over the same spectrum resources (that is frequency, code, time, and space) with different power levels, at minimized inter-user interference (IUI) [1,2]. In NOMA based wireless communication system, superimposition of message signals from multiple users in power domain is

carried out by making use of the channel gain of the respective users. Also, successive interference cancellation (SIC) is applied for multiuser detection and decoding at the receiver.

In NOMA systems, two types are generally common and are called power domain NOMA (PD-NOMA) and code domain NOMA (CD-NOMA). For the PD-NOMA, the same spectrum resources are efficiently



shared by different users at different power levels by superposition principle that enables lower channel gain users to be served with higher power and higher channel users to be served with lower power. The use of SIC schemes at the receivers to separate multiuser signals brings about significant increase in spectral efficiency in PD-NOMA [3]. The SIC technique is used to successively decode users' signals at their individual receiver while treating other users signal as interference. In the case of CD-NOMA, signal transmission is further categorized into sparse code multiple access (SCMA) and low-density signatures (LDS). The type considered in this paper is the PD-NOMA.

Some authors have presented NOMA based system in literature. Mbachu and Ibe [4] carried out performance improvement of MIMO-NOMA in multiuser scenario. Mathematical equations that describe the dynamics and characteristics of multiple antenna NOMA downlink system were used to develop MATLAB models used to carry out the performance analysis via simulations. Meghana *et al.* [5] presents a comprehensive performance comparison between OFDMA and NOMA under various wireless system configurations. Xie *et al.* [6] proposed a system of 6G Internet of Things (IoT) based on downlink non-orthogonal multiple access (NOMA) technology, where the base station (BS) allows signals of the same frequency to serve users at different distances. Jiménez *et al.* [7] analyzed the performance of a downlink multi-user multiple-input multiple-output (MU-MIMO) non-orthogonal multiple access (NOMA) communications system. Abood and Hburi [8] investigated the performance of NOMA and the power allocation strategy utilized on BER. Performance of NOMA technique based multiple user downlink wireless communication system was carried in Kabir [9]. Achebe [10] presented a technique to mitigate high Peak-to-Average Power Ratio (PAPR) in OFDM systems, a challenge that resulted in signal distortion and reduced power amplification efficiency. Muoghalu, *et al* [11] evaluated how these systems handled data transmission errors and analyzed the best modulation schemes to improve signal quality, likewise, Muoghalu, *et al* [12] investigated how scaling the

number of sensors impacted network efficiency in Wireless Sensor Networks (WSNs). Achebe and Okwueze [13] analyzed the performance of spatial receive diversity techniques-specifically Maximum Ratio Combining (MRC), Equal Gain Combining (EGC), and Selection Combining (SC)-within Massive MIMO systems to enhance SNR and channel capacity, Achebe and Muoghalu [14] compared how accurately two Minimum Mean Square Error (MMSE) receiver Algorithms-Linear MMSE and MMSE with Successive Interference Cancellation (MMSE-SIC)-decode signals from multiple users.

To provide communication service among multiple users over single channel, multiple access technique has been implemented. In contrast to conventional multiple access schemes such as orthogonal multiple access (OMA) and orthogonal frequency division multiple access (OFDMA) like in Egbunugha, *et al* [15] who proposed a hybrid approach combining Discrete Fourier Transform (DFT) precoding with repeated clipping and filtering to reduce high Peak-to-Average Power Ratio (PAPR) in OFDM systems and this technique minimized signal distortion and prevented spectral leakage, enhancing transmitter efficiency in high-speed wireless communications. By addressing inefficiencies in signal transmission, Eziuzo, *et al* [16] proposed a combined precoding and distortion technique to minimize the high Peak-to-Average Power Ratio (PAPR) in OFDM-based Cognitive Radio systems using a MATLAB-simulated hybrid approach, the study effectively reduced signal spikes and improved energy efficiency. NOMA is seen as promising method to solve these challenges for 5G and next generation wireless network because it offers improved user fairness, limited number of connected users, latency, and robustness. However, the main problem with NOMA is inter-user interference (IUI). Therefore, this paper attempts to implement NOMA using multiple antennas at transmitter and with more receive antennas with increased number of users to potentially enhanced BER as a metric to measure system transmission capacity with respect to users' equipment.

2. METHODOLOGY

Modelling of the System

The structure of the considered configuration in this paper is shown in Figure 1. In the system, due to inter user interference (IUI), SIC is used at each user's equipment to eliminate this challenge. In NOMA, information is transmitted to all user simultaneously.

The transmitted signals from the base station (BS) antennas to the user equipment, UE are $x_1(t)$, $x_2(t)$, and $x_n(t)$ over wireless channel, H, which is $n \times n$ vector of the multiple paths or channels taken by each transmitted signal to reach the UE. It should be noted that in this paper, three users are considered such that $x_n(t) = x_3(t)$, where $n = 3$.

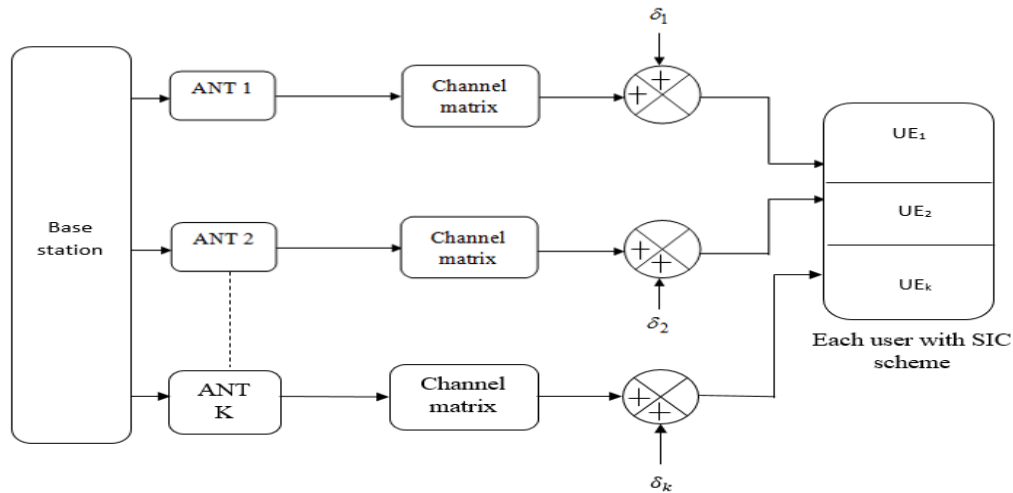


Figure 1: Designed MIMO-NOMA system configuration

The mathematical expressions for the process in terms of the received signals, the wireless channel H are given in Equations (1) and (2):

$$\begin{cases} y_1(t) = H_{11}x_1(t) + H_{12}x_2(t) + H_{13}x_3(t) + \sigma_1(t) \\ y_2(t) = H_{21}x_1(t) + H_{22}x_2(t) + H_{23}x_3(t) + \sigma_2(t) \\ y_3(t) = H_{31}x_1(t) + H_{32}x_2(t) + H_{33}x_3(t) + \sigma_3(t) \end{cases} \quad (1)$$

$$H = \begin{bmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & H_{33} \end{bmatrix} \quad (2)$$

where $y_1(t)$, $y_2(t)$ and $y_3(t)$ are the received signals from the BS to antennas, and $\sigma_1(t)$, $\sigma_2(t)$ and $\sigma_3(t)$ are the noise components on the receive antenna nodes, respectively. It should be noted that $y_3(t) = y_k(t)$, where $k = 3$. Equation (1) can further be simplified as:

$$y(t) = Hx(t) + \sigma(t) \quad (3)$$

where $y(t) = [y_1(t) \ y_2(t) \ y_3(t)]^T$ is the received vector signal, $x(t) = [x_1(t) \ x_2(t) \ x_3(t)]^T$ is the transmitted vector signal, and $\sigma(t) = [\sigma_1(t) \ \sigma_2(t) \ \sigma_3(t)]^T$ is the additive white Gaussian noise (AWGN) at each UE with mean zero.

Mathematical Description of System Performance Parameters

In this subsection, the various performance parameters used to evaluate the NOMA system for 5G application are presented.

Bit Error Rate and Signal to Noise Ratio

The ratio of the number of received bits containing errors to the sum of transmitted bits of data stream for a given time is called Bit error rate (BER) [8]. The BER equation is mathematically expressed as in Panwar and Kumar [17]:

$$BER = \frac{\text{Received erroneous bits}}{\text{Total number of bits}} \quad (4)$$

Conversely, signal to noise ratio (SNR) is expressed

as the power of signal to the power of noise in a wave, and it stands as the metric for comparing the desired signal strength to the background noise strength [8,18]. It is defined mathematically as:

$$SNR = \frac{\text{Signal power}}{\text{Noise power}} = \frac{P_s}{\sigma^2} \quad (5)$$

Simulation Parameters

The performances of the NOMA downlink systems were analyzed for varied SNR, and with respect of system bandwidth, channel gains for users' equipment, noise density, and power consumed by the circuitry of the transmitter. The parameters for system simulation in MATLAB are listed in Table 1.

Table 1 Simulation parameters

Definition	Value
Average channel gain of UE-1	h1 = -160 dB
Average channel gain of UE-2	h2 = -140 dB
Average channel gain of UE-3	h3 = -120 dB
Power allocation coefficients	$\alpha_k = 0:0.01:1$
Transmission power of single antenna	1 W
Channel state information (CSI)	Perfectly known at receiver (assumed)
Channel	Rayleigh fading
Distance of users from BS	Varied
Power consumed by circuitry	100 W
Noise density	-150dbW/Hz
System bandwidth	5 MHz
Number of symbols	32

3. RESULTS AND DISCUSSION

The BER performance of the MIMO-NOMA system is evaluated in this section considering three users: UE-1, UE-2, and UE-3. For the simulation

configuration, the first user (UE-1) is assigned the longest distance from the base station (BS) and therefore called the farthest user. The second user (UE-2) is assigned a longer distance than the third user (UE-3) and it is regarded as the mid user. The

UE-3 is allocated the shortest distance and is called the nearest user. Simulations were carried assuming that the users were simultaneously communicating with base station (BS). Simulations were conducted under constant path loss taken as 2 dB, while the users' distances increased from (100, 60, 40) to (120 80 60) metres for UE-1 to UE-3, respectively, the

SNR (signal power) was varied from 70 to 90 dB. The resulting simulated BER waveforms when the distances of the users from the BS were 100, 60, and 40 m under varied SNR are shown in Figures 2-4 The numerical results of the simulated BER waveforms are listed in Table 2.

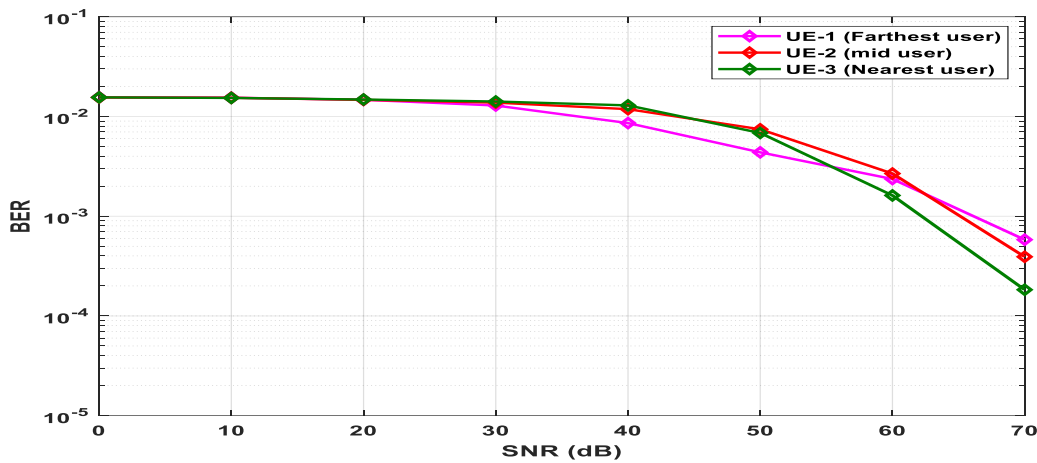


Figure 2: BER performance with distance 100, 60, 40 and SNR = 70 dB

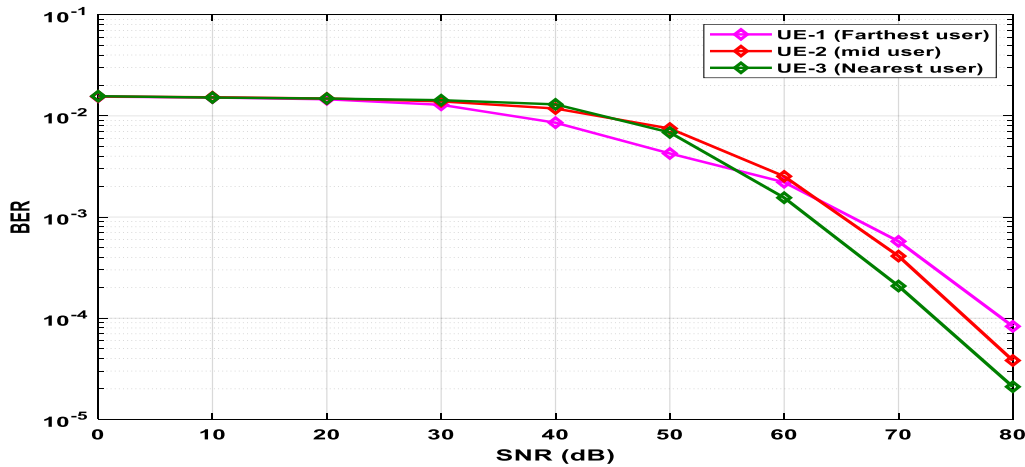


Figure 3: BER performance with distance 100, 60, 40 and SNR = 80 dB

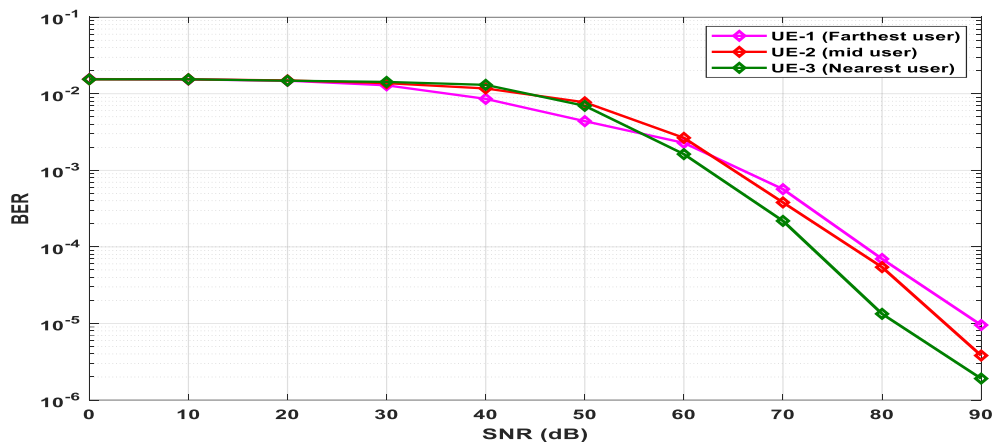


Figure 4: BER performance with distance 100, 60, 40 and SNR = 90 dB

Table 2: BER for varied SNR and user distance: 100, 60, and 40 m

User	BER		
	SNR = 70 dB	SNR = 80 dB	SNR = 90 dB
UE-1	0.00056	0.000083	0.0000095
UE-2	0.00042	0.000038	0.0000038
UE-3	0.00022	0.000021	0.0000019

From Figures 2-4 and Table 2, it can be seen that by keeping the distance of the users from the BS constant while increasing the SNR, the BER at each user’s receiver was improved. An obvious observation is that the higher the signal strength or power (i.e. SNR in dB), the better the BER, such that with SNR = 90 dB, the finest BER was achieved at each UE.

Furthermore, Figures 5-7 show the simulated BER waveforms of the system with distances of the users located at 120, 80, and 60 m, respectively. The numerical values of the BER achieved in each simulated scenario for the system’s BER performance analysis are listed in Table 3.

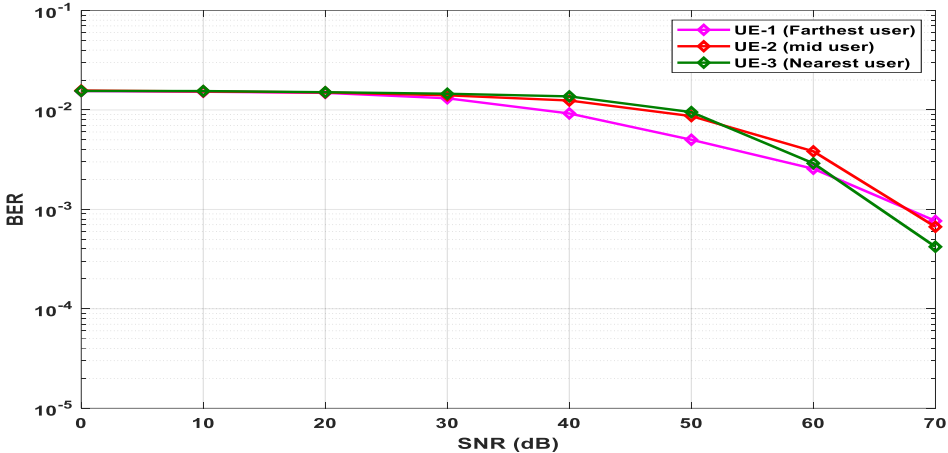


Figure 5: BER performance with distance 120, 80, 60 and SNR = 70 dB

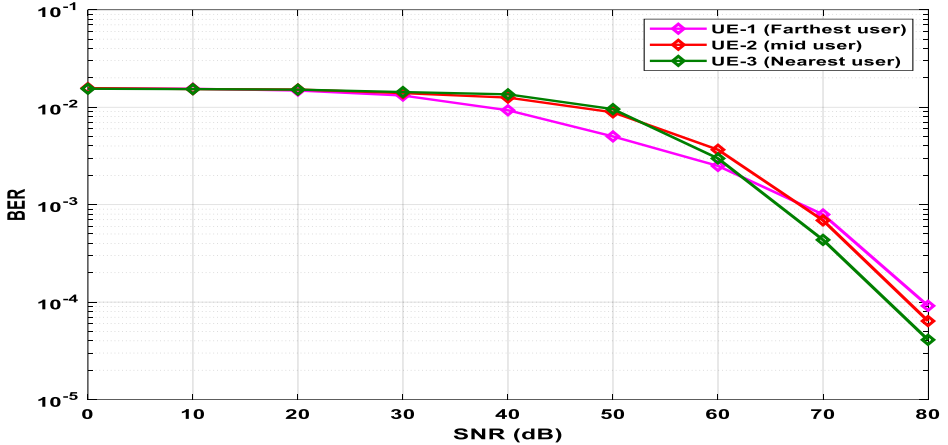


Figure 6: BER performance with distance 120, 80, 60 and SNR = 80 dB

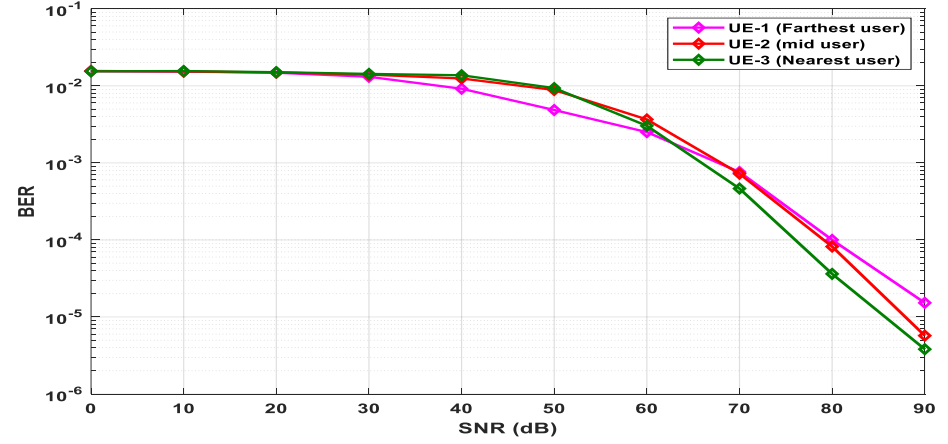


Figure 7: BER performance with distance 120, 80, 60 and SNR = 90 dB

Table 3: BER for varied SNR and user distance: 120, 80, and 60 m

User	BER		
	SNR = 70 dB	SNR = 80 dB	SNR = 90 dB
UE-1	0.00076	0.000092	0.000015
UE-2	0.00067	0.000064	0.0000057
UE-3	0.00042	0.000041	0.0000038

Again, the simulation results as presented in Figures 5-7 and Table 3, indicate that increase in SNR resulted in improved BER. This is an indication that increasing the strength of the transmitted signal the received signal capacity will be improved because the error in the signal is largely reduced compared to the data bit received. Another obvious observation is that the nearer the user to the BS the better the quality of signal received. Also, it can be seen, the BER achieved by each user when the distance was lesser in the first case was better than that of the case when distance of each user was increased by 20 m in the second scenario.

Now, considering the BER performance of each user, the user with the poorest BER was UE-1 which was located at the farthest distance from the BS. The user with the highest quality of signal reception in terms of BER was UE-3 and was located at the nearest location to the BS. Generally, from the analysis so far, the user (UE-1) achieved the least BER in all cases and it is considered the weakest users. Also, user (UE-3) achieved the best BER and it is called the strongest user.

The simulation of BER performance at each UE has shown that the analysis of the MIMO-NOMA system basically focused on the activities of the far and near user with the BS. Hence, in subsequent analysis, only the simulated waveform of the far and near users will be presented to simplify the analysis of the system performance.

4. CONCLUSION

The performance of multiple antenna-based NOMA downlink system has been evaluated with three users communicating with a BS at different distances. The entire analysis was conducted via computer-based simulation in MATLAB environment. The system was analyzed in terms of BER. The MATLAB simulation analysis revealed that the nearest user (UE-3) achieved the best BER, while the farthest user (UE-1) achieved the least performance. With the signal strength varied in terms of SNR in dB, it was observed that the BER performance improved as the SNR increased from 70 dB to 90 dB. Also, further increase in the users' distances from the BS, indicated that the BER at each user equipment (UE) decreased.

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