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PERFORMANCE IMPROVEMENT OF A WIRELES COMMUNICATION NETWORK USING MULTIPLE ANTENNA NON-ORTHOGONAL MULTIPLE ACCESS (NOMA) TECHNIQUE

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ABSTRACT

In recent research study, non-orthogonal multiple access (NOMA) has been shown to be one of the radio access technologies that is 5G compatible in the sense that it practically increases the spectral efficiency of system latency reduction. This work presents performance evaluation of multiple antenna non-orthogonal multiple access (NOMA) system in multiuser scenario. The objective is to analyse a multiple-antenna NOMA system 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. The simulations were evaluated in terms of two performance metrics namely, Bit Error Rate (BER) against Transmit power (dBm) and achievable sum rates. The results from the simulations conducted in terms of BER against Transmit power in dBm, revealed that the near user equipment (UE-1) has better performance (BER of 2.0e-06) than the far user equipment (UE-2) (of BER =.2.4e-05) at 40 dBm with distance of UE-2 from the base station (BS) equal to 500m. Further simulation by reducing the distance of the UE-2 to 300m showed that the BER of both users improves such that UE-1 has BER of 0, while for UE-2, it was 3e-06 at Transmit power of 40 dBm. The achievable sum rate curve of Multiple- Input Multiple -Output (MIMO) NOMA system revealed that it increases exponentially as the transmit power increases such that the outcome was a value of 20.75 bps/Hz at transmit power of 40 dBm. Further simulation of achievable sum rates of UE-1 and UE-2 indicated that the near user has a value of 18.75 bps/Hz as against 1.999 bps/Hz for the far user. This performance was achieved when the distance of the UE-2 equal to 500m. With the distance of UE-2 equal to 300m, the achievable sum rates of UE-1 and UE-2 were 18.75 bps/Hz and 2 bps/Hz respectively. Hence, with these results for different distances of UE-2 from the BS revealed that distance of user does not significantly influence achievable sum rate performance. In addition, performance of the MIMO-NOMA was compared with Multiple-Input Multiple-Output-Orthogonal Multiple Access (MIMO-OMA). Simulation results revealed that the MIMO-NOMA downlink system outperformed the MIMO-OMA in terms of achievable sum rate. In the case of comparison of users in both MIMO-NOMA and MIMO-OMA, the result of the analysis revealed that the user in MIMO-NOMA yielded better achievable sum rate than the user in MIMO-OMA. The system can be used for 5G network application.

Key Words: Non-Orthogonal Multiple Access, 5G, Wireless Communication, Antenna, and Bit Error Rate.

INTRODUCTION

New technology solutions are being sought after for the fifth generation (5G) and future cellular networks to ensure that mobile communication services are sustained in the next decades (Ali, 2017). Considering the expected exponential increase in mobile traffic, it is anticipated that these technologies will offer significant improvement in spectral efficiency as well as system capacity and enhance the experience of users. In this case, a scheme that has been considered promising for multiple access technology for 5G networks is non-orthogonal multiple access (NOMA). The fundamental concept of NOMA is that it serves multiple users at the same time over the same spectrum resources (that is frequency, code, time, and space) although at different power levels, at reduced inter-user interference (IUI) (Benjebour et al., 2015; Saito et al., 2013). NOMA can provide a considerable spectral efficiency gain and improved user experience by simultaneously serving multiple users in the same spectrum resources but at different power levels compared to conventional orthogonal multiple access (OMA) systems where each user is served (or schedule) on exclusively allocated spectrum resources. Hence, the basic concept of NOMA is that at the transmitter, it superimposes the message signals of multiple users in power domain by making use of the channel gain of the respective users. Then at the receiver, successive interference cancellation (SIC) is applied for multiuser detection and decoding. There are generally, two common types of NOMA systems namely, code domain NOMA (CD-NOMA) and power Domain NOMA (PD-NOMA). The transmission of signals in the case of CD-NOMA, is further categorized into many techniques that are low density signatures (LDS) and sparse code multiple access (SCMA) dependent. Inter-symbol interference (ISI) is minimized by LDS technique. The LDS scheme comprises sparse spreading codes where each consists of some non-zero elements. The generation of more unique codewords is enabled by sparse spreading codes for signal transmission which then permits the orthogonal superimposition of more users. At the receiver, user’s separation can be performed even when the power levels of the users are of the same characteristics. Frequency diversity and overloading can be achieved by employing LDS for multiple access and orthogonal frequency division multiplexing (OFDM) for multicarrier modulation because of their sparse spreading and orthogonal mapping (Poojala and Vedavalli, 2021). However, this approach can result in high receiver complexity and as well be expensive. Optimizing the sparse spreading code by combining LDS and quadrature amplitude modulation (QAM) mapping to generate codewords occurs in SCMA (Nikopour and Baligh, 2013). Thus, a moderate complexity is achieved at the receiver because of the transparent codewords between transmitter end and receiver (Elsaraf et al., 2018). In the PD-NOMA system, different users are allowed to efficiently share the same spectrum resources with different power levels by the principle of superposition in order that lower channel gain users are served with higher power and the same holds in opposite order. Spectral efficiency significantly increases in PD-NOMA by using SIC technique at receivers to isolate multiuser signals. The use of SIC technique ensures that user signals are successively decoded at their separate receiver while other user signal is treated as interference. Thus there is the benefit of removing the signals as user signal reaches the next receiver. In this work, the focus is on PD-NOMA and it is designed to improve the performance of multiple antenna NOMA system in multiuser scenario.

LITERATURE REVIEW

Kabir and Ullah (2017) carried out performance evaluation of 2 × 2 multiuser downlink Multiple-Input Multiple-Output Non-Orthogonal Multiple Access system for colour image transmission. The system considered was simulated incorporating various schemes for signal processing such as convolutional channel coding, low density parity checks (LDPC) channel coding, digital modulation: (quadrature phase shift keying (QPSK), differential quadrature phase shift keying (DQPSK), and fourth order quadrature amplitude modulation (4-QAM)), and signal detection. Simulation study in MATLAB revealed that the system was very much robust and efficient in retrieving transmitted colour images underutilization of LPDC channel coding and 4-QAM modulation schemes when downlink transmission of encrypted colour image of each of the two users in a hostile fading channel was considered. The performance parameter for evaluating the system was bit error rate (BER) against signal to noise ratio (SNR).

Ahmed et al. (2022) carried out a study on the performance evaluation of the MIMO NOMA wireless communication system for the transmission of various types of data (images) to different users at the same time. The simulation results of the system showed that it was possible to transmit various types of data to different users in the MIMO-NOMA wireless communication system which the authors claimed meets one of the major requirements of the next generation wireless communication system like Beyond 5G (B5G) and 6G. It was also observed from the simulation analysis that the BER performances are very much robust and satisfactory with binary phase shift keying (BPSK) and 4-QAM techniques and conventional channel coding schemes. The simulation results of the system also revealed that power allocation among the users significantly affects the performance of the system, far user deserves more power than the near user for implementing NOMA. Considering the system performance, the study concluded that NOMA was suitable for simultaneously transmitting different data over the additive white Gaussian noise (AWGN) channel in a hostile fading environment. Figure 1 shows the block diagram of the system.

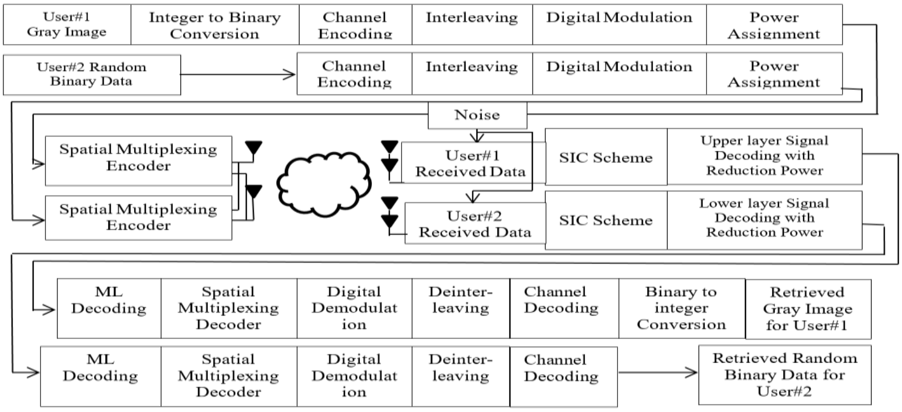

Figure 1: Block diagram of MIMO NOMA system (Ahmed et al., 2022)

Suprith and Ahmed (2022) described NOMA as one of the promising technologies for wireless radio access networks in 5G. It stated that when compared to orthogonal multiple accesses (OMA), it reduces the spectral efficiency. NOMA provides the best solution by increasing the data rates. The authors then evaluated NOMA with a downlink in the automatic deployment of multiuser. The outage performance and ergotic sum-rate gain give the NOMA better performance can be concluded at the final results. NOMA provides the Quality of Service (QoS) to the multi-users by considering the power allocation and data rate factors. The study considered the outage probability will be 1 when different users are identified and the data rate and power allocated.

Multiple Access

In wireless communication system, to provide communication service between multiple transmitters and receivers simultaneously over a single channel by using channelization techniques based on time, frequency or code is known as multiple access. The channels are created by dividing the resources orthogonally or semi-orthogonally. The transmitting power of each transmitter may be different, but the receiver's bandwidth is divided among the users. The principle of multiple access technology is utilizing the available resources like bandwidth and power in an efficient manner while creating minimum or no interference. Generally, when dedicated channel allocation is done to the users, it is called multiple access. It is commonly used in the telephone systems as they use dedicated channel allocation for voice signals. The sharing of bandwidth which require burst transmissions by using random channel allocation and which does not assure channel access is called random multiple access. The choice of random access or multiple access and channelization type to be used will depend on the characteristics and compatibility of the system. By sharing the bandwidth, overall channel capacity is increased (Goldsmith, 2005). Multiple access is categorized into two namely, orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA) (Islam et al., 2016). Nguyen et al. (2022) stated that the introduction of 5th and 6th –generation wireless networks has elevated the demand for huge device connectivity, spectral efficacy, and improved signal quality. The authors maintained that non-orthogonal multiple access technique (NOMA) has been demonstrated to be a candidate to address these requirements. NOMA can assist many users using the same resource block by varying the assigned power levels fairness to the users. In order to perform this, the NOMA technique superimposes the signals from both the users and transmits them to the receiver. On the receiver side, it performs successive interference cancellation (SIC) techniques to separate the respective signals. Meanwhile, the fading channels also play a major role in deciding the quality of the signal that is being transmitted. In the study, a NOMA system was considered in presence of two users having two fading channels. The closed-form mathematical equation describing the system characteristics were derived for outage probability and throughput of the system in presence of perfect SIC and imperfect SIC. The equations were numerically analyzed by varying various parameters such as fading channels, power level coefficients, and the number of antennas at the receivers. The obtained results demonstrate that each parameter plays a major role in enhancing the quality of each user's signal and the outage performance of the system. Son and Le Khoa (2021) described Multiple-input multiple-output (MIMO) technique combined with non-orthogonal multiple access (NOMA) as wireless communication technique that has been considered to enhance total system performance. The study carried out performance analysis of the bit error rate (BER) of two-user power-domain NOMA systems using successive interference cancellation receivers, with zero forcing (ZF) equalization over quasi-static Rayleigh fading channels. Successive interference cancellation technique at NOMA receivers has been the popular research topic due to its simple implementation, despite its vulnerability to error propagation. Closed-form mathematical equations representing the dynamic characteristics of the system were derived for downlink NOMA in single-input single-output and uncorrelated quasi-static MIMO Rayleigh fading channel. The authors used quadrature phase shift keying (QPSK) modulation technique and considered only two users scenario.

Orthogonal Multiple Access

Orthogonal Multiple Access (OMA) technique scheme divides the available resources (power or bandwidth) of the system equally and then assign to the users through the channels. It is a technique used in wireless communication systems to enable multiple users to access the same network resources simultaneously. It is a method of allowing several users to share the same frequency band by allocating orthogonal codes to each user (Islam et al., 2016). In traditional multiple access schemes, such as Time Division Multiple Access (TDMA) or Frequency Division Multiple Access (FDMA), users are allocated different time slots or frequency bands to transmit their data. However, these methods are not very efficient in terms of utilizing the available network resources, especially in scenarios with varying bandwidth requirements. OMA allows multiple users to transmit simultaneously in the same frequency band, improving the spectral efficiency of the network. This is achieved by assigning orthogonal codes to each user, which ensures that the signals transmitted by different users do not interfere with each other (Saito et al., 2013). One of the most commonly used OMA techniques is Orthogonal Frequency Division Multiple Access (OFDMA). In OFDMA, the available frequency band is divided into subcarriers, with each subcarrier carrying separate information for different users. These subcarriers can be dynamically allocated to users depending on their varying bandwidth requirements. This flexibility in allocating subcarriers enables efficient utilization of the available spectrum. Another variant of OMA is Code Division Multiple Access (CDMA), where each user is assigned a unique spreading code. The spreading codes are orthogonal to each other, allowing multiple users to transmit their signals simultaneously. CDMA is widely used in cellular networks, such as 3G to accommodate numerous users and provide high data rates (Cui et al., 2018). OMA techniques offer several advantages over traditional multiple access schemes. Firstly, they allow for efficient use of network resources, as multiple users can access the network simultaneously. This leads to increased capacity and higher data rates. It provides flexibility in allocating resources to different users based on their requirements, ensuring efficient utilization of the available spectrum and enables better resistance to interference, as the orthogonal codes or subcarriers minimize the impact of overlapping transmissions. However, implementing OMA in practical systems comes with challenges. One of the main challenges is the design and synchronization of orthogonal codes or subcarriers to ensure proper orthogonality. OMA requires more complex signal processing techniques compared to traditional multiple access schemes, which can increase the complexity and cost of the system (Wang et al., 2006). Despite these challenges, OMA techniques have gained significant attention and have become the foundation of various wireless communication standards.

Non-Orthogonal Multiple Access (NOMA)

Non-Orthogonal Multiple Access (NOMA) is an advanced wireless communication technique that is gaining significant attention in research and industries (Ding et al., 2014; Saito et al., 2013). As the demand for wireless services continues to grow exponentially, traditional orthogonal multiple access (OMA) techniques, such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA), are facing limitations in terms of spectrum efficiency. NOMA, on the other hand, offers an innovative solution by allowing multiple users to share the same time-frequency resources, enabling higher capacity, improved throughput, and enhanced spectral efficiency. NOMA fundamentally differs from traditional OMA techniques by allowing multiple users to share the same time-frequency resources non-orthogonally. This is achieved by applying successive interference cancellation (SIC) at the receiver, which enables simultaneous demodulation of multiple user signals (Saito et al., 2013; Kimy et al., 2013; Lei et al., 2017). NOMA assigns different power levels and codes to different users (Nikopour and Baligh, 2013), allowing overlapping transmissions and efficient utilization of the available spectrum resources. By decoding stronger signals first and removing their effects from subsequent weaker signals, NOMA achieves a higher spectral efficiency compared to OMA techniques. Additionally, NOMA can support a larger number of users within the same bandwidth, further enhancing capacity and system performance. NOMA can be separated into two common categories: code domain NOMA (CDNOMA) and power domain NOMA (PD-NOMA) but this work focus mainly on (PD-NOMA). This scheme offers several advantages over traditional OMA techniques, making it a promising technology for future wireless communication systems. Firstly, NOMA improves spectral efficiency (Alavi et al., 2017) by enabling multiple users to share the same resources non-orthogonally, resulting in higher throughput and increased capacity. By exploiting user diversity in terms of signal strengths, NOMA ensures better utilization of the available resources. NOMA provides low latency and high reliability, making it suitable for delay-sensitive applications like Internet of Things (IoT) and real-time multimedia streaming. NOMA enables better fairness among users by offering a higher data rate to users with poor channel conditions, ensuring a more equitable distribution of resources (Elsaraf and Baligh, 2018). While NOMA brings unprecedented benefits to wireless communication, it also poses certain challenges that need to be addressed for successful deployment. One key challenge is the implementation complexity at the receiver, as the SIC process requires precise channel state information (CSI) and robust interference cancellation algorithms. The overhead associated with CSI acquisition and synchronization must be minimized to reduce complexity and energy consumption. Interference management and power allocation techniques play a crucial role in optimizing the performance of NOMA systems. Advanced signal processing algorithms, such as advanced multi-user detection and beamforming, can be employed to mitigate interference and improve system performance. NOMA has the potential to revolutionize various wireless communication scenarios and applications. In cellular networks, NOMA can be used to enhance the capacity and coverage of existing systems, leading to improved network performance and user experience. By enabling efficient spectrum sharing, NOMA can support massive machine-type communications in IoT networks, facilitating the seamless connectivity of a large number of low-power IoT devices. NOMA is also well-suited for 5G and beyond-5G networks, where it can significantly enhance data rates, spectral efficiency, and system capacity (Ding et al., 2015; Islam et al., 2018).

The Prospect of the NOMA System

As a potential multiple access technique for 5G mobile communication systems, NOMA is receiving tremendous interests from communication research society. NOMA demonstrates a significant enhancement of spectral efficiency gain without requiring any additional infrastructure/resources. Although inter-user interference is the main obstacle for NOMA, efficient user clustering and power allocation can minimize inter-user interference and can provide high spectral efficiency performance. On the other hand, by using multiple antennas at the transmitter and receiver ends, MIMO technique can potentially multiply the spectral efficiency gain in proportion to the spatial multiplexing order. The inter-user interference in MIMO can be completely eliminated when the number of total receive antennas is equal to or less than the total transmit antennas in a cell. However, in MIMO-NOMA, the number of receive antennas is more than the number of transmit antennas, thus the resultant interference for each user is very high. Therefore, another insight is to develop a “robust" multiuser MIMO-NOMA system for downlink transmission which can minimize the net interference, and thus maximize the system capacity. In addition, the coordinated multi-point (CoMP) technology for downlink transmission is a promising approach to enhance the quality of user experience (QoE) for interference-prone users, particularly for cell-edge users, by exploiting the co-channel inter-cell interferences. In downlink NOMA, a cell-edge user usually gets low signal-to-inter-user-interference-plus-noise ratio (SINR). Therefore, in co-channel multi-cell downlink NOMA, the use of CoMP is crucial to enhance QoE for cell-edge users.

METHODOLOGY

Research Design

In order to carry out the performance improvement of the designed multiple antenna non-orthogonal multiple access (NOMA) system in multiuser scenario implemented in this work, certain numerical simulations were conducted in MATLAB environment, which yielded result in generation of graphs.

System Model

Figure 2 is a description of the multiuser multiple antenna NOMA system model considered in this work. It represents a downlink MU MIMO-NOMA network that comprises a base station (BS) that transmits desired signal and at different power allocation coefficients β_1 and β_2, to number of users (UE-1 and UE-2).Let the distances of UE-1 and UE-2 from the BS be d_1 and d_2. It is assumed that distance of UE-2 from the BS is longer than that of UE-1 such that $d_2 > d_1$. Hence, UE-1 is regarded as strong user while UE-2 is considered the weak user based on their nearness to the base station. In this work, the MIMO antenna is used to achieve diversity gain so as to decrease bit error rate (BER). The block diagram of the system is shown in Figure 3. The expressions δ_1 and δ_2 are the channel noise.

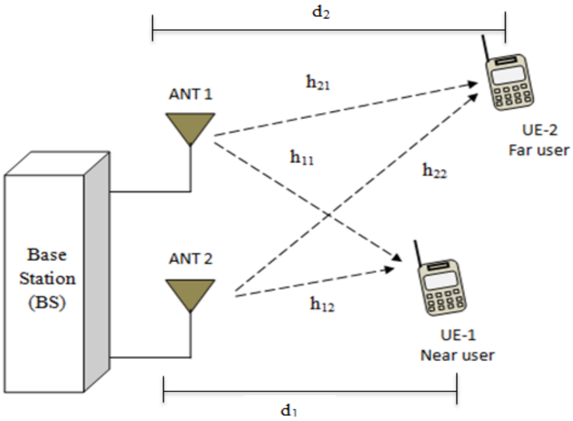

Figure 2: Multiuser MIMO-NOMA downlink system model

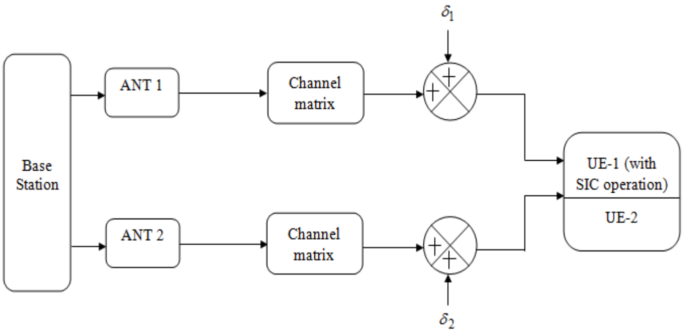

Figure 3: Proposed block diagram model

Mathematical Description of Signal Model

In this work, considering the system model in Figure 2, the BS is assumed to be transmitting signals from two M transmit antennas ANT 1 and ANT 2 to two single-cell users at distance d$_1$ and d$_2$ using NOMA technique over Rayleigh fading channels. With power allocation factors β_1 and β_2, assigned to the respective jth user equipment, the transmitted signal is given by:

$$s = \sqrt{\mathrm{P_s}}\left(\sqrt{\beta_1} s_1 + \sqrt{\beta_2} s_2\right)$$

Or simplified further as:

$$s = \sqrt{\mathrm{P_s}}\sqrt{\beta_1} s_1 + \sqrt{\mathrm{P_s}}\sqrt{\beta_2} s_2 \qquad (1)$$

where P$_\mathrm{s}$ is the transmission power from the base station (that is the total average energy available at the BS in one symbol period). It should be noted that $\beta_1 < \beta_2$ because UE-2 is the weaker user.

Now, at the receiver, the transmitted s received by the various users as a complex signal vector influenced by the channel characteristics and noise and since it is transmitted by the transmit antennas at the same time to the users, it is expressed as follows with respect to each user.
For first user (UE-1):

$$r_1 = s\mathrm{h}_{11} + s\mathrm{h}_{12} + \delta_1 = s\left(\mathrm{h}_{11} + \mathrm{h}_{12}\right) + \delta_1 \qquad (2)$$

For second user (UE-2):

$$r_2 = s\mathrm{h}_{21} + s\mathrm{h}_{22} + \delta_2 = s\left(\mathrm{h}_{21} + \mathrm{h}_{22}\right) + \delta_2 \qquad (3)$$

where δ_1 and δ_2 are additive white Gaussian noise (AWGN) with zero mean and variance, σ^2
The next approach is to describe the mathematical expression for the decoding operations at the UE-1 and UE-2, which represents the performance metrics for the system.

Performance Metrics

In this section, the various performance metrics considered in evaluating the proposed system are briefly discussed. These are achievable rate, BER, and power allocation.

Achievable Rate

The first user equipment, UE-1 must decode s_1 from r_1. Since UE-1 is the near user, its signal s_1 is assigned less power. Thus, in r_1, the power of the transmitted signal s_2 will be dominating (that is s_2

will over shadow or dominate s_1 since it is allocated more power coefficient). Hence, UE-1 has to carry out direct decoding on r_1 to determine s_2. This requires SIC do be performed in order to eliminate s_2 and afterward, s_1 is decoded.

The SIC process is as follows:

Step 1: At this stage, the transmitted signal s is directly decoded to obtain the signal s_2, which is weighed with high power.

Step 2: Here, the directly decoded signal s_2 in step 1 is multiplied by its corresponding weight β_2 and then subtracted from the transmitted signal s.

Step 3: This stage involves decoding the signal resulting from step 2 to obtain the other signal, s_1 which weighed (or multiplexed) with low power.

Considering the SIC process described, the expression for the achievable sum rate for UE-1 is determined as follows. Substituting Equation (1) for s into Equation (2) gives:

$$r_1 = (\sqrt{P_s}\sqrt{\beta_1}s_1 + \sqrt{P_s}\sqrt{\beta_2}s_2)(h_{11} + h_{12}) + \delta_1 \quad (4)$$

Expanding Equation (4) gives:

$$r_1 = \underbrace{\sqrt{P_s}\sqrt{\beta_1}s_1(h_{11} + h_{12})}_{\text{desired}} + \underbrace{\sqrt{P_s}\sqrt{\beta_2}s_2(h_{11} + h_{12})}_{\text{undesired (dominating signal)}} + \delta_1 \quad (5)$$

Since more power is allocated to UE-2 by the BS, that is, $\beta_1 < \beta_2$, the UE-1 cannot decode its own signal directly. It must first decode the strong signal s_2. The signal interference to noise ratio (SINR) at UE-1 on decoding of s_2 is given by:

$$SINR_{12} = \frac{\left|\sqrt{P_s}\sqrt{\beta_2}s_2(h_{11} + h_{12})\right|^2}{\left|\sqrt{P_s}\sqrt{\beta_1}s_1(h_{11} + h_{12}) + \delta_1\right|^2} \quad (6)$$

Simplifying Equation (6) gives:

$$SINR_{12} = \frac{P_s\beta_2|h_{11} + h_{12}|^2}{P_s\beta_1|h_{11} + h_{12}|^2 + \sigma^2} \quad (7)$$

Hence, after SIC process, the undesired signal in Equation (7) is removed since UE-1 knows the exact interference term from the signal s_2. Therefore, the resultant received signal at UE-1 after the SIC process is given by:

$$r_1' = \sqrt{P_s}\sqrt{\beta_1}s_1(h_{11} + h_{12}) + \delta_1 \quad (8)$$

At this point, the UE-1 can now decode its signal given in Equation (3.10). The resulting SINR (or signal to noise ratio) at UE-1 is given by:

$$SINR_{11} = \frac{\left|\sqrt{P_s}\sqrt{\beta_1}s_1(h_{11} + h_{12})\right|^2}{\sigma^2} = \frac{P_s\beta_1\left|(h_{11} + h_{12})\right|^2}{\sigma^2} \quad (9)$$

Thus the achievable sum rates at UE-1 for decoding s_1 and s_2 are expressed as:

$$R_1 = \log_2(1 + SINR_{11}) \quad (10)$$

$$R_2 = \log_2(1 + SINR_{12}) \quad (11)$$

On the other hand, the UE-2 can directly decode its own signal since it considers the s_1 as a low noise signal (i.e., a weak signal). Thus, UE-2 can directly decode s_2 from r_2, while treating s_1 as interference. Substituting s in Equation (1) into Equation (3) gives:

$$r_2 = (\sqrt{P_s}\sqrt{\beta_1}s_1 + \sqrt{P_s}\sqrt{\beta_2}s_2)(h_{21} + h_{22}) + \delta_2 \quad (12)$$

Expanding Equation (12) gives:

$$r_1 = \underbrace{\sqrt{P_s}\sqrt{\beta_1}s_1(h_{21} + h_{22})}_{\text{desired}} + \underbrace{\sqrt{P_s}\sqrt{\beta_2}s_2(h_{21} + h_{22})}_{\text{interference}} + \delta_1 \quad (13)$$

Now, the SINR for the process of decoding signal s_2 at UE-2 is given by:

$$SINR_{22} = \frac{P_s\beta_2|h_{21} + h_{22}|^2}{P_s\beta_1|h_{21} + h_{22}|^2 + \sigma^2} \quad (14)$$

The achievable sum rate at UE-2 is expressed as:

$$R_3 = \log_2(1 + SINR_{22}) \quad (15)$$

Bit Error Rate and Signal to Noise Ratio

Bit error rate (BER) is defined as the ratio of the number of received bits containing errors to the sum of transmitted bits of data stream for a given time (Abood and Hburi, 2022). The BER equation is mathematically expressed as in Panwar and Kumar (2012):

$$\mathrm{BER} = \frac{\text{Received errorneous bits}}{\text{Total number of bits}} \tag{16}$$

On the other hand, signal to noise ratio (SNR) describes the power of signal to the power of noise in a wave, and represents the metric for comparing the desired signal strength to the background noise strength (Shafik et al., 2006; Abood and Hburi, 2022). It is defined mathematically as:

$$\mathrm{SNR} = \frac{\text{Signal power}}{\text{Noise power}} = \frac{P_s}{\sigma^2} \tag{17}$$

Simulation Parameters

In order to investigate the performance of the multiple antenna NOMA system with multiple users' scenario, this section presents the simulation parameters taken from related work carried out by Son and Le Khoa (2021) with modification to include distances of users from the base station, path loss gain, and number of symbol. The definition and values of the parameters are shown in Table 1. The design and implementation flowchart is shown in Figure 4.

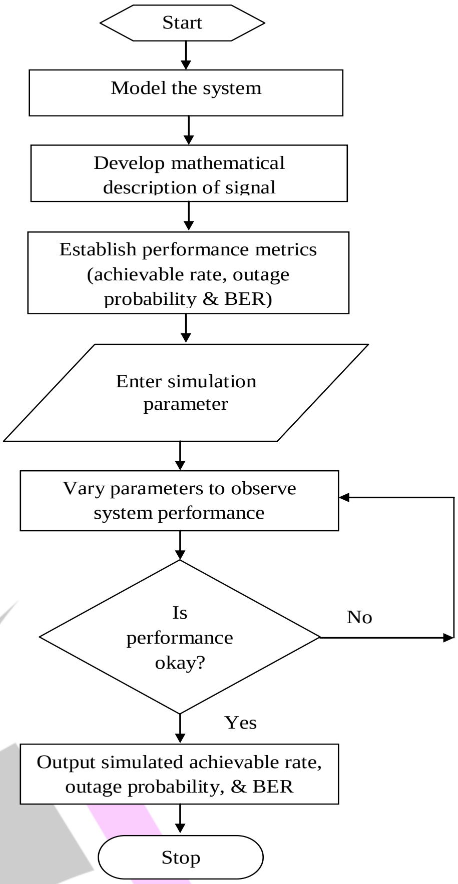

Figure 4: Design and simulation flowchart

RESULTS

In this section, results obtained from simulation analysis conducted in MATLAB are presented in terms of the performance metrics considered above. Simulations were carried out first for MIMO-NOMA and then compared with MIMO-OMA using BPSK modulation scheme. Generally, the performance evaluation of the multiuser system was done using different data in a typical downlink MIMO-NOMA wireless communication. The simulation process was considered assuming the channel state information (CSI) of the Rayleigh fading channel is known at the receiver.

MIMO-NOMA System

Here, the simulation results are presented for multiuser MIMO-NOMA downlink system assuming two users UE-1 and UE-2 communicating with a base station (BS) simultaneously. The system was evaluated in this case for BER and achievable sum rates.

Table 1 Simulation parameters

Definition	Value
Average channel gain of UE-1	$g_1 = 1$
Average channel gain of UE-2	$g_2 = 0.5$
Power allocation coefficients	$\beta_1 = 0.25,\ \beta_2 = 0.75$
Transmission power of single antenna	$P_s = 1$
Channel state information (CSI)	Perfectly known at receiver (assumed)
Channel	Rayleigh fading
Distance of users from BS	$d_1 = 200, d_2 = 500$
Path loss exponent	$P_l = 4$
Number of symbol	10^6

BER Analysis

The simulation results obtained for MIMO-NOMA system considering two users such that UE-1 is a near user and UE-2 is taken as the far user is shown in Figure 5 in terms of BER performance curves assuming the distances of the users to be 200m and 500m. Further simulation was conducted by varying distance of UE-2 from 500m to 300m and the BER performance is shown in Figure 6. The resulting numerical values from analyses of the curves are shown in Table 2.

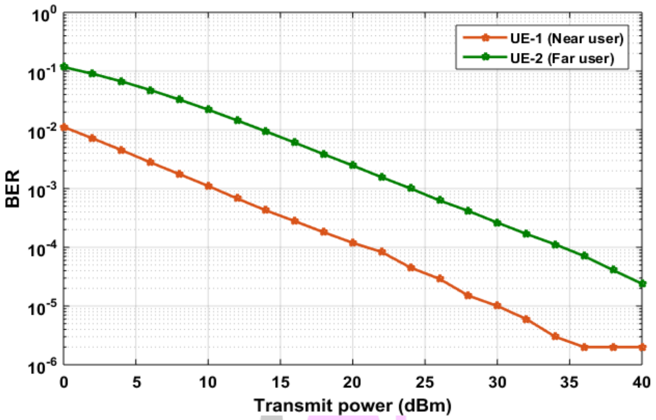

Figure 5: BER performance of two users in MIMO-NOMA system ($d_2 = 500$m)

The BER simulation curves of the multiuser MIMO-NOMA system assuming two users communicating to a base station (BS) at different distances $d_1 = 200$m and $d_2 = 500$m presented in Figure 6.

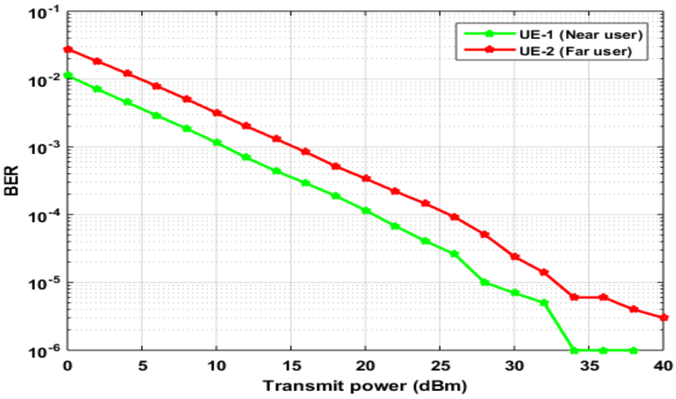

Figure 6: BER performance of two users in MIMO-NOMA system ($d_2 = 300$m)

Table 2: Numerical analysis of BER performance of two users in MIMO-NOMA system

Transmit power (dBm)	$d_1 = 200$, $d_2 = 500$		$d_1 = 200$, $d_2 = 300$	
	UE-1 (near user)	UE-2 (far user)	UE-1 (near user)	UE-2 (far user)
0	0.01121	0.1173	0.01122	0.002761
2	0.007158	0.09015	0.007089	0.01831
4	0.004523	0.06679	0.004527	0.001206
6	0.002794	0.04756	0.00289	0.007861
8	0.001761	0.03275	0.00185	0.00504
10	0.001106	0.02204	0.001154	0.003175

12	0.000678	0.01445	0.000693	0.002013
14	0.000424	0.009387	0.00044	0.001303
16	0.000278	0.006031	0.000291	0.000836
18	0.00018	0.003837	0.000189	0.00517
20	0.000119	0.002462	0.000116	0.00034
22	8.3e-05	0.001557	6.8e-05	0.00022
24	4.5e-05	0.001002	2.1e-05	0.000146
26	2.9e-05	0.000627	2.6e-05	9.2e-05
28	1.5e-05	0.000415	1e-05	5.1e-05
30	1.0e-05	0.000263	7e-06	2.4e-05
32	6.0e-06	0.000169	5e-06	1.4e-05
34	3.0e-06	0.000112	1e-06	6e-06
36	2.0e-06	7.1e-05	1e-06	6e-06
38	2.0e-6	4.1e-05	1e-06	4e-06
40	2.0e-6	2.4e-05	0	3e-06

Looking at Table 2, it can be seen from the numerical analysis of each simulation curve of BER against transmit power for UE-1 and UE-2 that the near user has better performance than the far user even though user 2 was assigned the higher power allocation this is because the UE-2 signal (or symbol) depends on UE-1 decoding. Further analysis carried out on the BER performance of the system by reducing the distance of the far user (UE-2) to 300m revealed that the BER performances of the users are improved as shown in Table 2 (d_1 = 200m, d_2 = 300m). The reason for the change in the distance of UE-2 affecting the BER performance of both users can be attributed to the fact that the information intended for UE-2 is obtained by UE-1 as established in Equation (15). That means that the information (Bits) sent to UE-2 is influenced by UE-1. It should be noted that the power allocation coefficients for the users remain the same.

Achievable Sum Rates

The simulation result of MIMO-NOMA downlink system is presented in terms of achievable sum rates performance metric as shown in Figure 7. Also, the resulting curves in terms of achievable sum rates for multiuser MIMO-NOMA downlink system assuming two users UE-1 and UE-2 communicating with BS at different distance, but the individual power allocation factor remains the same as shown in Figures 9 and 10 for d_2 = 500m and d_2 = 300m respectively

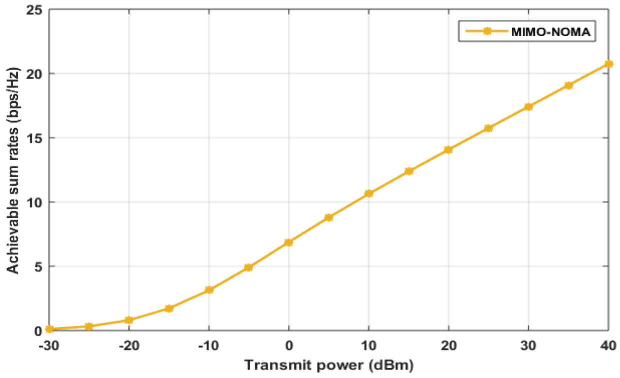

Figure 7: Achievable sum rate plots of MIMO-NOMA downlink system

Figure 8 is the achievable sum rate of MIMO-NOMA system, but not individual achievable sum rate. The simulation curve shows that the achievable sum rate increases as the transmit power (in dBm) increases. Thus, the achievable sum rate of the multiuser MIMO-NOMA downlink system is 20.75 bps/Hz at transmit power of 40 dBm.

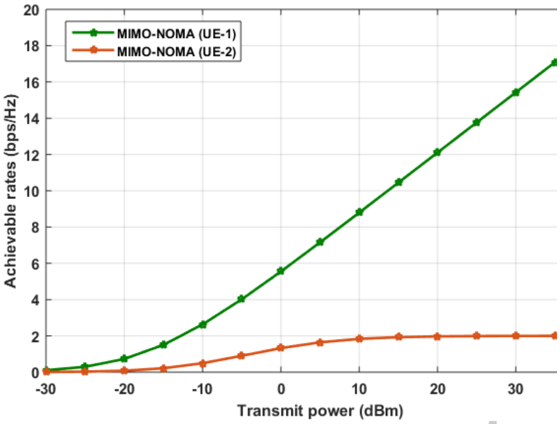

Figure 8: Achievable sum rate plots of individual user (d_2 = 500m)

Figure 8 shows the individual achievable sum rates of users in the network when d_2 = 500m. Similar to the achievable sum rates of the MIMO-NOMA system, the curves for the users increases as the transmit power increases. It can be seen that the near user (UE-1) has better achievable sum rate than the far user (UE-2). Simulation results indicated that each of UE-1 and UE-2 has achievable sum rates of 18.75 bps/Hz and 1.999 bps/Hz at transmit power of 40 dBm respectively.

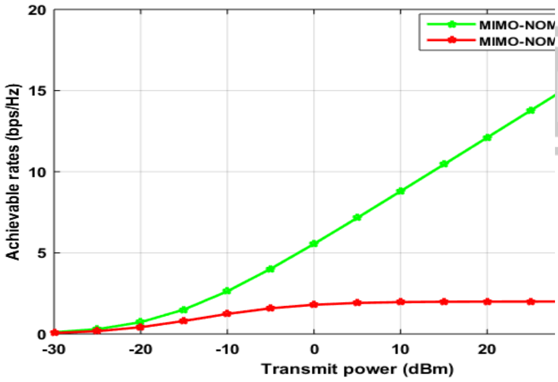

Figure 9: Achievable sum rate plots of individual user (d_2 = 300m)

The achievable sum rates for d_2 = 300m is shown in Figure 9. In this case, the simulation result indicated the achievable sum rate for UE-1 is 18.75 bps/Hz and 2 bps/Hz at transmit power of 40 dBm respectively. Thus, from the achievable sum rate performances shown in Figures 8 and 9, it is obvious making the distance of far user closer to the first user did not cause any significant increase or change in the achievable sum rate of UE-2. This shows that distance of user does not influence achievable sum rate performance.

Performance Comparison

This section covers the results obtained from the simulation analyses carried out to compare the performance of the multiuser MIMO-NOMA downlink system against conventional multiuser MIMO-OMA downlink system developed in this work. The comparison was done for achievable sum rate for MIMO-NOMA and MIMO-OMA downlink systems shown in Figure 10. Further comparison was done for individual achievable sum rate between two near users in MIMO-NOMA and MIMO-OMA as shown in Figure 10.

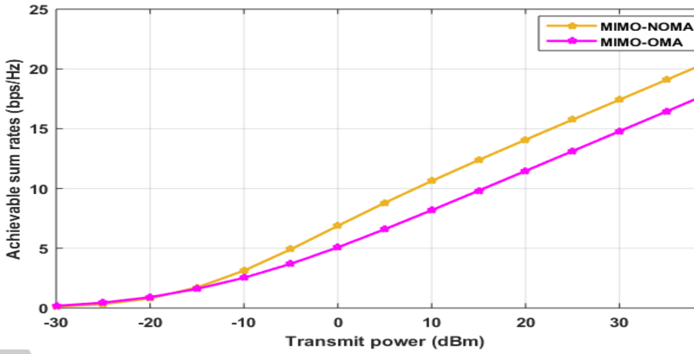

Figure 10: comparison of achievable sum rates of MIMO-NOMA and MIMO-OMA

The achievable sum rates of MIMO-NOMA and MIMO-OMA are compared as shown Figure 11. From the simulation curves, it was observed that the MIMO-NOMA downlink system offered achievable sum rate of 20.75 bps/Hz while the MIMO-OMA downlink system yielded 18.11 bps/Hz.

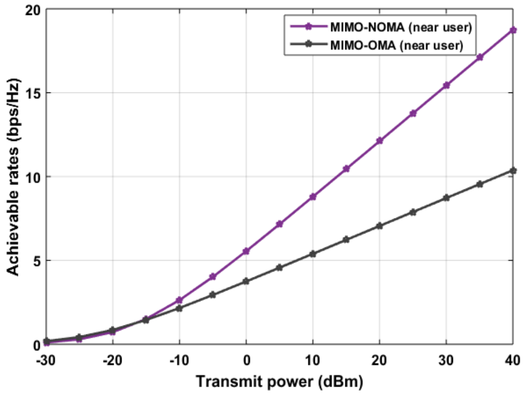

Figure 11: Individual achievable sum rates of MIMO-NOMA and MIMO-OMA

The achievable sum rates simulation curves shown in Figure 11 are for two near users in MIMO-NOMA and MIMO-OMA downlink systems. The results revealed that the near user in MIMO-NOMA has an achievable sum rate of 18.75 bps/Hz while that of the near user in MIMO-OMA is 10.37 bps/Hz.

SUMMARY OF DISCUSSION

The performance analysis of the NOMA system in multiuser scenario has been carried out via simulations in MATLAB. The simulations were evaluated in terms of two performance metrics namely, BER against transmit power (dBm) and achievable sum rates. The results from the simulations conducted as shown Figure 5, revealed that the near user (UE-1) has better performance than the far user (UE-2). Further simulation by reducing the distance of the UE-2 showed that the BER of both users increase as the distance between them decreases. This should be expected because the information (Bits) sent to UE-2 is influenced by UE-1. The achievable sum rate of MIMO-NOMA system revealed that achievable sum rate increases exponentially as the transmit power increases such that the outcome was a value of 20.75 bps/Hz at transmit power of 40 dBm. Further simulation of achievable sum rates of UE-1 and UE-2 indicated that the near user has a value of 18.75 bps/Hz as against 1.999 bps/Hz for the far user. This performance was achieved when the distance of the UE-2 equal to 500m. With the distance of UE-2 equal to 300m, the achievable sum rates of UE-1 and UE-2 were 18.75 bps/Hz and 2 bps/Hz respectively. Hence, with these results for different distances of UE-2 from the BS revealed that distance of user does not significantly influence achievable sum rate performance. In addition, performance of the MIMO-NOMA was compared with MIMO-OMA. Simulation results revealed that the MIMO-NOMA downlink system outperformed the MIMO-OMA in terms of achievable sum rate. In the case of comparison of users in both MIMO-NOMA and MIMO-OMA, the result of the analysis revealed that the user in MIMO-NOMA yielded better achievable sum rate than the user in MIMO-OMA.

CONCLUSION

In this work, performance analysis of NOMA system in multiuser scenario has been presented. The use of multiple antenna at the transmit and receive ends respectively with NOMA will give rise to wireless communication system that leverages the spatial multiplexing configuration of the MIMO scheme that would be able to multiply the spectral efficiency gain and as such improve system performance. The basic concept of this work was to analyze the performance of multiple users in a multiple antenna NOMA downlink system. This was evaluated in terms of BER and achievable sum rate. In order to ensure that transmitted signal meant for UE-2 did not overshadow or dominate the signal for UE-1 because of its higher power allocation, a signal interference cancellation (SIC) scheme was introduced and used to carry out elimination of the far user from that of the near user. The BPSK modulation technique was employed for signal transmission over Rayleigh channel. 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. The resulting performance revealed that near user in NOMA system achieved better performance than far user. Furthermore, comparison of the MIMO-NOMA with conventional MIMO-OMA revealed its superiority.

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