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Research Article

Performance Analysis of Orthogonal Multiple Access and Non-Orthogonal Multiple Access

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Abstract: Non-orthogonal multiple access (NOMA) as one of the upcoming and promising multiple access technologies has a significant impact on the development of the 5G wireless communication systems. A detailed description of downlink system model is illustrated by using mathematical equations. Multiple-input multiple-output (MIMO) communications with multi-user is a promising technology for optimizing overall system throughput, based on number of BS transmit antennas and total number of receive antennas at the user ends in the cell, each user is provided by one or multiple beams in downlink multiuser MIMO. In MIMO-NOMA channel gains are assembled into groups. This paper discusses the concept of non-orthogonal multiple access (NOMA) scheme for the future radio access for 5G to provide the fundamentals of the technique for downlink channel and then discuss optimizing the network capacity under fairness constraints. also further discuss the impacts of number of users on the performance of NOMA networks.

Keywords: Orthogonal Multiple Access, Non-Orthogonal Multiple-Input Multiple-Output, Bit Rate, Energy, Spectral Efficiency.

1. Introduction

The fast growth of the mobile technology where data traffic is expected to be increased 1000 times in 2020's caused complicated requirements for the fifth generation (5G) of wireless communication systems [1]. Different users are assigned to orthogonal resources in the frequency or time domain in orthogonal multiple access (OMA). Unlike the OMA, Non-orthogonal multiple access (NOMA) allows multiple users to utilize the entire available frequency and time resources simultaneously time, resulting in higher spectral efficiency than OMA techniques [2]. A NOMA technology was suggested for 5G cellular systems as a candidate communication system, typically NOMA systems that can be classified into several categories, most particularly: Power-domain multiplexing and multiplex code-domain [3].

Power-domain NOMA is a helpful technology 5G wireless communication system. It enables multiple users to share the same time-frequency resources by employing superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver. This approach offers higher spectral efficiency compared to traditional orthogonal multiple access (OMA) schemes. Many studies have demonstrated that NOMA a greater sum rate than OMA. Which is theoretically and practically proven in a cellular downlink scenario with randomly distributed users.

Also, NOMA delivers enhanced spectral efficiency (SE) [4]. The superposition coded signal can be properly decoded and demodulated at the receiver by applying successive interference cancellation (SIC) in the NOMA systems [5]. Multiple-input multiple-output (MIMO) communications with multiuser is a promising technology for optimizing overall system throughput, based on number of BS transmit antennas and total number of receive antennas at the user ends in the cell, each user is provided by one or multiple beams in downlink multiuser MIMO [6].

In this paper the downlink multiuser MIMO-NOMA is presented based on power domain utilizing, and the performance is evaluated compared with the conventional OMA in order to optimize the achievable bit rate, spectral efficiency and outage probability, the study also includes the impact of number of users and transmit and receive antennas configuration, by estimation of bet error rate with varied signal to noise ratio values.

2. Non-Orthogonal Multiple Access Schemes

The underlying concept of NOMA is very divergent as compared to the traditionally studied OMA schemes. NOMA supports numerous users to communicate with the same code and frequency simultaneously with varying power levels. As stated earlier in NOMA, power allocation is according to the channel conditions. This means that users which are experiencing better channel gains will be assigned less power. Every user, however, will extract its own data with the application of SIC [7]. NOMA is further classified into cooperative and non-cooperative schemes.

A. Cooperative NOMA

In cooperative NOMA, the prior information available in NOMA systems is fully exploited. The cooperative NOMA relay scheme performs much better under the presence of slow fading source-to-relay link as compared to the non-cooperative method. The BSs are supposed cooperate with each other for the down link transmission.

B. NOMA Multiple Relay Channel

NOMA with multiple relay channel is considered as a multi-terminal network that consists of independent users that are attempting to access destination via independent relays. The outage achievable rate is derived for the NOMA with multiple relay channel. For relay channel, according to a joint network-channel coding concept, the intermediate nodes of the network can alternatively work as a sender and a receiver [8].

C. Non-Cooperative NOMA

Unlike cooperative NOMA, non-cooperative NOMA does not have any information about the wireless network available prior to transmission. Non-cooperative NOMA is extensively studied as the most common schemes [9]. The cooperative and non-cooperative NOMA are described as shown in Figure 1.

3. Power Domain Non-Orthogonal Multiple Access (PD-NOMA)

The key idea behind PD-NOMA principle is multiplexing using power diversity. While studying PD-NOM three of the foremost terminologies that will be frequently used/referred are: channel difference between users, power splitting and successive interference cancellation (SIC). As its principal approach, PD-NOMA allocates different power to multiple users with different channel conditions, sends the superimposed signal to the users which then decode their signal using SIC.

SIC involves decoding and subtracting/removing message of user with better channel condition such that self-message can be decoded with lower interference from the superimposed signal. For de-multiplexing of the signals at the receiver it is favorable that the difference in allocated power is sufficiently large. This implies that the difference in channel condition between the users multiplexed using NOMA should also be sufficiently large. The impact of channel gain difference between the users on the performance gain achieved by NOMA where the power allocation in NOMA primarily depends on the channel gain difference between the users and hence plays a vital role in the performance of NOMA systems [10].

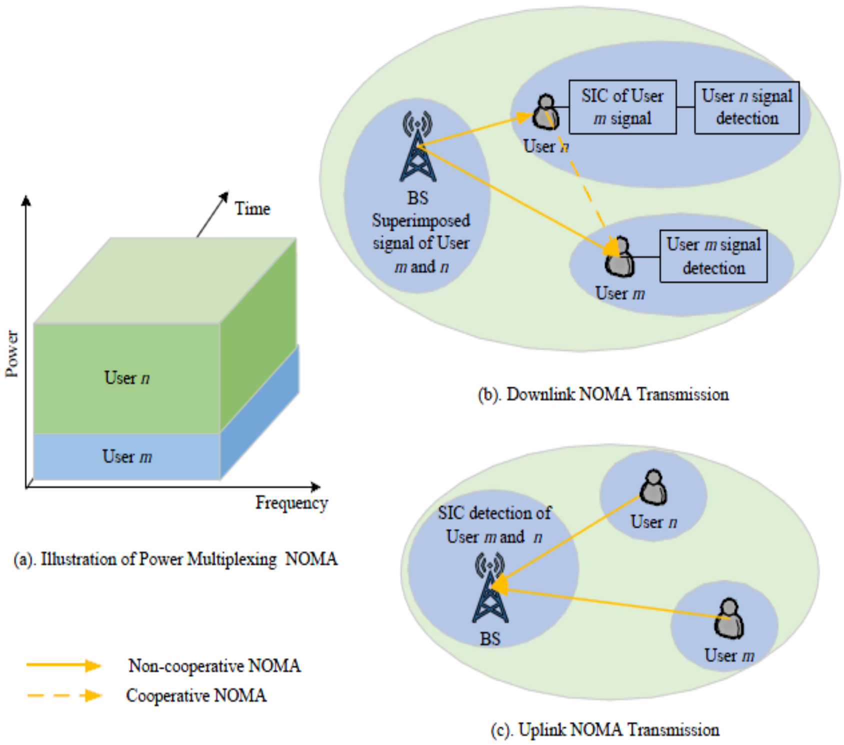

Figure 1. Illustration of NOMA transmission.

The basic idea of power allocation in NOMA is different from power control, but the algorithm follows similar procedure. Also, different from the conventional power splitting techniques which allots more power to users with better channel condition, in PD-NOMA the power allocation is inversely proportional to the channel condition of the user. This implies that a weak user, i.e., a user with poor channel condition will be awarded larger power. This balances the trade-off between system throughput and user fairness which imposes prime importance in any wireless communication system. The traditional power splitting technique achieve better overall system performance, however, at the cost of weak user's throughput [11]. The concept of PD-NOMA is illustrated in Figure 2.

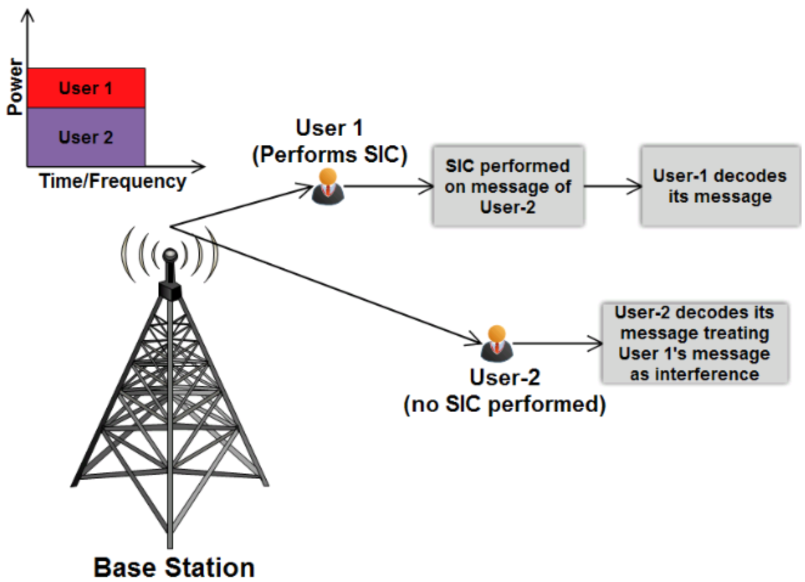

Figure 2. Basic Concept of PD-NOMA.

4. Key Technologies of NOMA

The key enabling technologies for NOMA is based on two principles, namely, Superposition Coding (SC) and Successive Interference Cancelation (SIC). In fact, these two technologies are not new and the roots of them can be found in many existing literatures. As the two main technologies SC and SIC continue to mature both in theoretical and practical aspects, NOMA is able to be applied in the next generation networks without considering the implementation issues. By invoking SC technique, the BS transmits the combination of superposition coded signals of all users' messages. Without loss of generality, the channel gains of users are with respect to a particular ordering (e.g., increasing order or decreasing order). In the traditional OMA schemes, one of the popular power allocation policies is water filling policy. However, in NOMA, users with poor channel conditions are supposed to allocate more power. By doing so, it can ensure that the users with poor channel condition can decode the message of themselves by treating other users' messages as noise. For those users which are in good channel conditions, SIC technologies can be applied to enable subtract the interference from other users with poorer channel conditions. Figure 3 illistrates typical M user NOMA communication scenario.

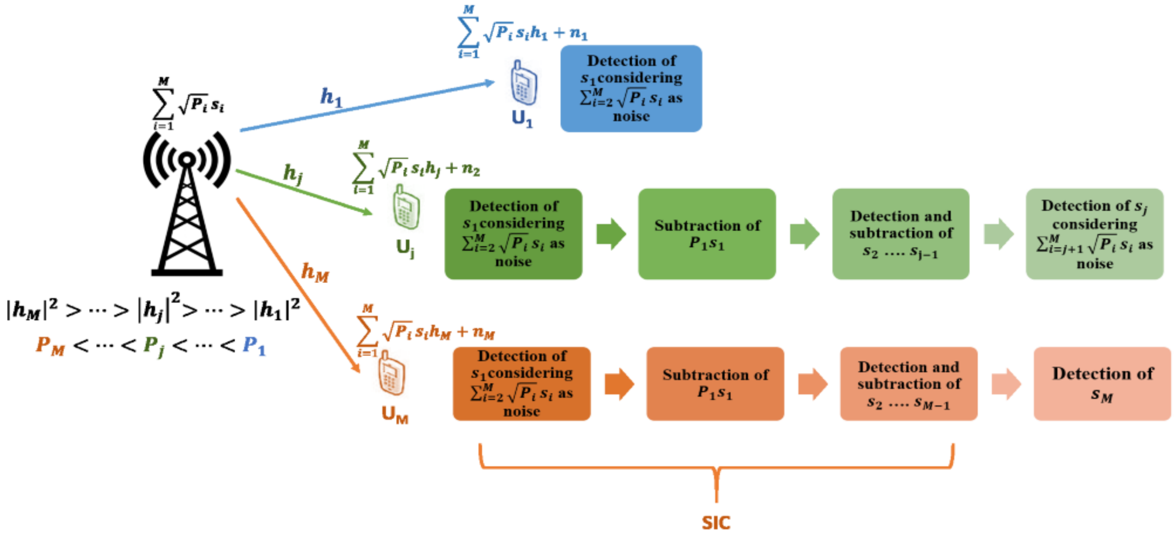

Figure 3. Typical M user NOMA communication scenario.

NOMA has been recognized as a strong candidate among all MA techniques since it has essential features to overcome challenges in counterpart OMA and achieve the requirements of next mobile communication systems. The superiority of NOMA over OMA can be remarked as follows:

A. Spectral efficiency and throughput

In OMA, such as in OFDMA, a specific frequency resource is assigned to each user even it experiences a good or bad channel condition; thus, the overall system suffers from low spectral efficiency and throughput. In the contrary, in NOMA the same frequency resource is assigned to multiple mobile users, with good and bad channel conditions, at the same time. Hence, the resource assigned for the weak user is also used by the strong user, and the interference can be mitigated through SIC processes at users' receivers.

B. User fairness, low latency, and massive connectivity

In OMA, for example in OFDMA with scheduling, the user with a good channel condition has a higher priority to be served while the user with a bad channel condition has to wait for access, which leads to a fairness problem and high latency. This approach cannot support massive connectivity.

C. Compatibility

NOMA is also compatible with the current and future communication systems since it does not require significant modifications on the existing architecture. For example, NOMA has been included in third generation partnership project long-term evolution advanced (3GPP LTE Release 13) [12]. The comparison between MIMO-NOMA and MIMO-OMA in this section includes the following measurements: achievable rates of users, achievable sum rates, Outage probabilities, and EE-SE trade-off curves.

5. The Performance Methodology

The comparison between MIMO-NOMA and MIMO-OMA in this section includes the following measurements: achievable rates of users, achievable sum rates, Outage probabilities, EE-SE trade-off curves, and bit error rate.

A. Achievable rates of users for downlink.

In NOMA downlink, a standard single-cell cellular system is considered which consists of one BS equipped with multiple antennas at transmitter, For MIMO-NOMA scheme, SC is employed at the transmitter side, i.e., the transmitted signals share the same frequency and time resources but vary in power. Thus, the signals transmitted from the BS are given by following equation (1).

$$x = \sqrt{P_t}\sum_{i=1}^{n}\sqrt{\alpha_i}\,x_i \tag{1}$$

Where:

P_t: Total power transmitter.

α_i: Power allocation coefficient for UE-*i.*

x_i: Signal transmitted for UE-*i.*

n : Number of UE.

The BS always sends data to all users simultaneously, subject to the constraint of total power $\boldsymbol{P_t}$, it is assumed that the wireless links experience independent and identically distributed (i.i.d.) block Rayleigh fading and additive white Gaussian noise (AWGN). The channels are sorted as $0 < |H_1|^2 < |H_2|^2 < \dots\dots < |H_i|^2 < \cdots < |H_n|^2$ which indicates that user UE-*i.* always holds ith the weakest instantaneous channel. The NOMA scheme allows simultaneous serving of all users by using the entire system bandwidth (BW) to transmit data with the help of SC at the BS and SIC decoding techniques at the users. Here, user multiplexing is executed in the power domain. The BS transmits a linear superposition of n users' data by allocating a fraction α_i of the total power to each UE-*i*, i.e., the power allocated for the user is $P_i = P_t\alpha_i$. where power allocation factor can be obtained as:

$$\alpha_i = \frac{d_i^2}{\sum_{k=1}^{n} d_k^2} \tag{2}$$

Where d_i is thr distance between i^th user and BS.

On the receiving end, each user decodes the signals of the weaker users UE-*i*, i.e., can decode the signals for each UE-m with $m < i$. The signals for weaker users are then subtracted from the received signal to decode the signal of user UE-*i*, it self-treating the signals of the stronger users UE-m, with $m > i$, as interference. The received signal at user UE-i can be represented as:

$$y_i = H_i x + w_i \tag{3}$$

where $H_i = \sum_{\boldsymbol{m=0}}^{\boldsymbol{M}}\sum_{\boldsymbol{n=0}}^{\boldsymbol{N}}\widehat{\boldsymbol{H}}_{\boldsymbol{mn}}$which is M × N Rayleigh flat-fading matrix channel between UE-*i*and the BS. Also, is the w_i AWGN of user UE-i with zero mean and varianceσ_n^2. If signal superposition at the BS, and SIC at UE-*i*, are carried out perfectly. The data rate achievable is given by following equation (4).

$$R_i = BW.log_2\left(1 + \frac{P_t\alpha_i|H_i|^2}{P_t|H_i|^2\sum_{k=i+1}^{n}\alpha_k + \sigma^2}\right) \tag{4}$$

Note that the data rate of user UE-n is written as following:

$$R_n = BW.log_2\left(1 + \frac{P_t\alpha_n|H_n|^2}{\sigma^2}\right) \tag{5}$$

As, this user successively decodes and cancels all other users' signals prior to decoding its own signal [13]. In this study the comparison of the achievable rates of MIMO-NOMA and MIMO-OMA includes three cases:

- Two-user in the system.
- Three-user in the system.
- Four-user in the system.

i. Two-User Case:

The base station transmits a signal for UE-*i*, (*i*=1, 2) with transmit power $\sqrt{P}\sqrt{\alpha_i}$In NOMA, $x1$ and $x2$ are superposed as follows:

$$x = \sqrt{P}\sqrt{\alpha_1}x_1 + \sqrt{P}\sqrt{\alpha_2}x_2 + \sigma_n^2 \tag{6}$$

According to the NOMA principle, the SIC decoding is implemented at the receiver of strong user, without loss of generality, assuming that user 2 is strong user and user 1 is weak user, which may indicate that user 2 is a central user while user 1 is at cell-edge. In this case, user 1 will decode its own symbol x_1 directly via treating the interference caused by x_2 as unknown interference, and then the achievable rate of user 1 is bounded by:

$$R_1 = BW.log_2(1 + SINR_1) \tag{7}$$

Then, $SINR_1$ equation for U1 in decoding x1 is written as following:

$$SINR_1 = \frac{P_t\alpha_1|H_1|^2}{P_t\alpha_2|H_1|^2 + \sigma_n^2} \tag{8}$$

For user 2, it will first decode the symbol vector x_1 via treating the interference caused by x_2 as unknown interference and then cancel the part of received signal caused by x_1 from received signal and decode x_2 from the remain part of received signal. Assuming that user 2 can decode x_1 at the codeword level, so the achievable rate of user 2 can be written as:

$$R_2 = BW.log_2(1 + SNR_2) \tag{9}$$

Finally, the SNR for U2 to decode its own signal is given by:

$$SNR_2 = \frac{P_t\alpha_2|H_2|^2}{\sigma_n^2} \tag{10}$$

ii. Three-user case:

$$R_1 = BW.log_2\left(1 + \frac{P_t\alpha_1|H_1|^2}{P_t\alpha_2|H_1|^2 + P_t\alpha_3|H_1|^2 + \sigma_n^2}\right) \tag{11a}$$

$$R_2 = BW.log_2\left(1 + \frac{P_t\alpha_2|H_2|^2}{P_t\alpha_3|H_2|^2 + \sigma_n^2}\right) \tag{11b}$$

$$R_3 = BW.log_2\left(1 + \frac{P_t\alpha_3|H_3|^2}{\sigma_n^2}\right) \tag{11c}$$

iii. Four-user case:

$$R_1 = BW.log_2\left(1 + \frac{P_t\alpha_1|H_1|^2}{P_t\alpha_2|H_1|^2\sum_{i=2}^{4}\alpha_i + \sigma_n^2}\right) \tag{12a}$$

$$R_2 = BW.log_2\left(1 + \frac{P_t\alpha_2|H_2|^2}{P_t\alpha_3|H_2|^2 + P_t\alpha_4|H_2|^2 + \sigma_n^2}\right) \tag{12b}$$

$$R_3 = BW.log_2\left(1 + \frac{P_t\alpha_3|H_3|^2}{P_t\alpha_4|H_3|^2 + \sigma_n^2}\right) \tag{12c}$$

$$R_4 = BW.log_2\left(1 + \frac{P_t\alpha_4|H_4|^2}{\sigma_n^2}\right) \tag{12d}$$

By using (6) and (7), and after some algebraic manipulations, the sum rate can be obtained as:

$$R_{sum} = BW.log_2 \left(1 + \frac{P_t\alpha_n|H_n|^2}{\sigma_n^2} + \sum_{i=1}^{n-1}\left(\frac{P_t\alpha_i|H_i|^2}{P_t|H_i|^2\sum_{k=i+1}^{n}\alpha_k + \sigma_n^2}\right)\right) \tag{13}$$

To maximize the total rate, OMA methods divide the degrees of freedom (time or frequency) among the users. In this section, the total bandwidth and power are shared among the UEs equally, the sum rate for each UE-i for OMA becomes as following [14].

$$R_i = \frac{1}{k} BW.log_2(1 + SNR_i) \tag{14}$$

Where:

R_i : Achievable rate for UE-*i*.

k : The number of users.

The SNR_i of UE-*i* is given by following equation (15):

$$SNR_i = \frac{P_i |H_i|^2}{\sigma_n^2} \tag{15}$$

B. Outage Probabilities Comparison.

Considering MIMO-NOMA systems, the user j is considered to be in outage when its fails to detect the message of user i , where $1 < j < i$This essentially implies that whenever user j is unable to decode (meets the targeted rate) any of the higher order user or its own message, then it will suffer from complete outage. the SINR at user j to decode the message signal of *i-th* user can be expressed as:

$$SINR_{j\to i} = \frac{\left|H_j\right|^2 \alpha_i P_t}{P_t \left|H_j\right|^2 \sum_{k=j+1}^{n} \alpha_k + \sigma_n^2} \tag{16}$$

Based on Equation (16), the outage probability at the *j-th* user in decoding *i-th* user message, can be expressed as follows:

$$P_{j\to i} = \Pr\left(\mathrm{R}_{j\to i} < \varphi_i\right) \tag{17a}$$

$$P_{j\to i} = \Pr\left(log_2\left(1 + \frac{\left|H_j\right|^2 \alpha_i P_t}{P_t |H_i|^2 \sum_{k=j+1}^{n} \alpha_k + \sigma_n^2}\right) < \varphi_i\right) \tag{17b}$$

$$P_j = \Pr\left(log_2\left(1 + \frac{\left|H_j\right|^2 \alpha_i P_t}{P_t |H_i|^2 \sum_{k=j+1}^{n} \alpha_k + \sigma_n^2}\right) < \varphi_i\right) \tag{17c}$$

$$\& \, Pr\left(log_2\left(1 + \frac{P_t \alpha_j \left|H_j\right|^2}{P_t \left|H_j\right|^2 \sum_{k=j+1}^{n} \alpha_k + \sigma_n^2}\right) < \varphi_j\right) \tag{17d}$$

Where $\varphi_{i,j}$is the targeted rate of user*i, j* $1 < j < i$.

By applying conventional MIMO-OMA, the outage probability experienced by the *i*-th ordered user is given by following equation [15]:

$$P_i = \Pr\left(\frac{1}{\mathrm{k}} log_2\left(1 + \frac{|H_i|^2 P_t}{\sigma_n^2}\right) < \varphi_i\right) \tag{18}$$

C. EE-SE Trade-off Curves

The next generation of wireless networks, namely 5G, aims at providing high data rate and system capacity. To enable sustainable 5G networks, new communication technologies have been proposed to ameliorate the system energy efficiency (EE). In particular, various 5G techniques have been proposed which aim to enhance the network throughput while consuming less energy without degrading the quality of service, in cellular networks, spectral efficiency (SE) is also an important performance measure. Moreover, nowadays users are employing multiple-antenna handsets while performing antenna selection can provide a higher flexibility to the system operator to achieve a balance between SE and EE With the rise in desire for energy efficient communications in recent years, reducing energy consumption has become of prime importance for researchers, and 5G has also targeted EE as one of the major parameters to be achieved, However, Shannon's information capacity theorem illustrates that the two objectives of minimizing consumed energy and maximizing SE are not achievable simultaneously, and calls for a trade-off. The SE and the EE are essentially used to estimate the NOMA systems performance [16]. EE is defined as the sum rate over the total consumed power of the base station. The equations of spectral efficiency and energy efficiency are written as following

$$EE = \frac{R_{sum}}{P_t} \text{(bits/joule)} \tag{19a}$$

$$SE = \frac{R_{sum}}{W} \text{(bps/Hz)} \tag{19b}$$

6. Simulation Results

This section introduces the performance of MIMO-NOMA systems compared to MIMO-OMA, the comparison analysis is evaluated in terms of different parameters: bit error rate, achievable rate, capacity, outage probability, and EE-SE trade-off. The BER comparison is based on number of users and channel models, where MIMO system is represented by multipath Rayleigh fading channel. Then, this model is applied on MIMO-OMA and MIMO-NOMA. Consider a 2-user downlink MIMO system as shown in Figure 4. Let d_1 and d_2 denote the distances of U_1 and U_2 respectively from the MIMO transmitter. Here, we assume $d_1>d_2$. That is, U1 is the weak user and U2 is the strong user.

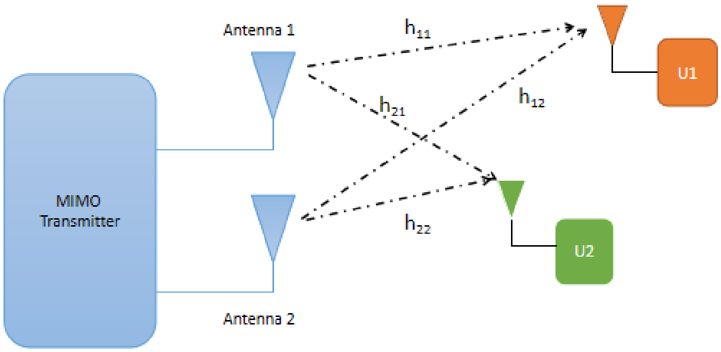

Figure 4. MIMO-NOMA System Model.

In this comparison system bandwidth is set as BW=1MHz, the thermal noise power is calculated as No=kTB, where k=1.38×10^{-23}J/K, and T=300ºK. Achievable rates for MIMO-NOMA and MIMO-OMA systems for each user are calculated with varying the transmit power, the individual rate for each user is calculated. Applying the cases of two-user, three-user, and four-user, the results are plotted as shown in Figure 5 to Figure 7.

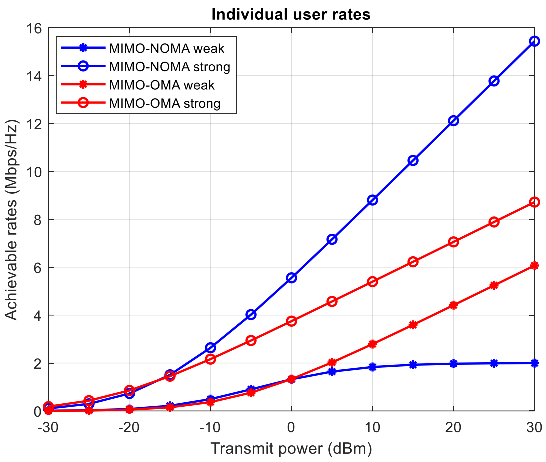

Figure 5. The Individual user rates performance for 2-user case.

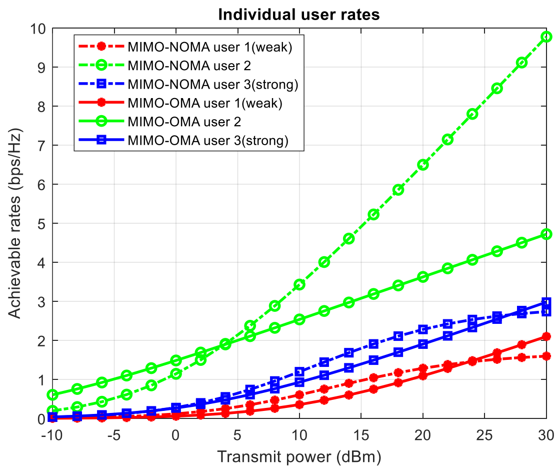

Figure 6. The Individual user rates performance for 3-user case.

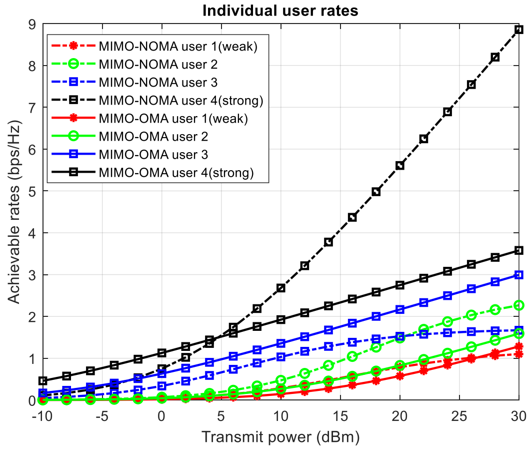

Figure 7. The Individual user rates performance for 4-user case.

MIMO NOMA for the first user has the best performance followed by the OMA rates of the two users then MIMO NOMA achieves much higher rates compared to MIMO OMA. The system capacity which is represented by the achievable sum rates obtained by summation of all users' rates and taking the average value that applied the cases of two-user, three-user, and four-user, the. The results are plotted as shown Figure 8 to Figure 10.

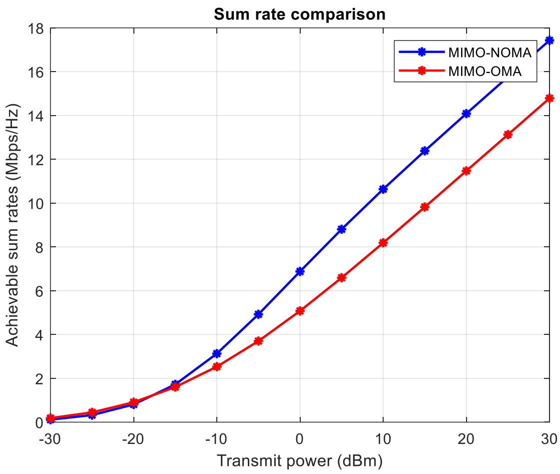

Figure 8. The capacity of user rates performance2-user case.

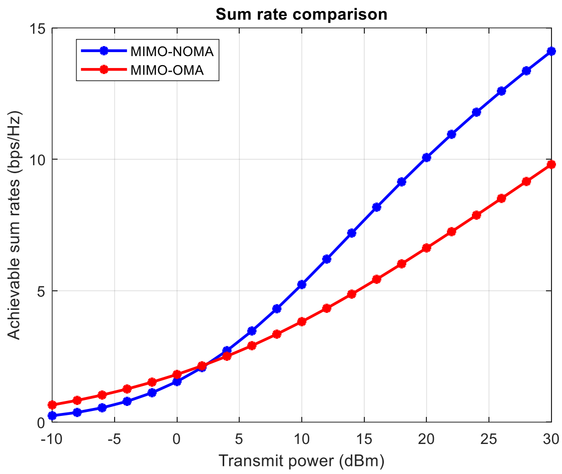

Figure 9. The capacity of user rates performance 3-user case.

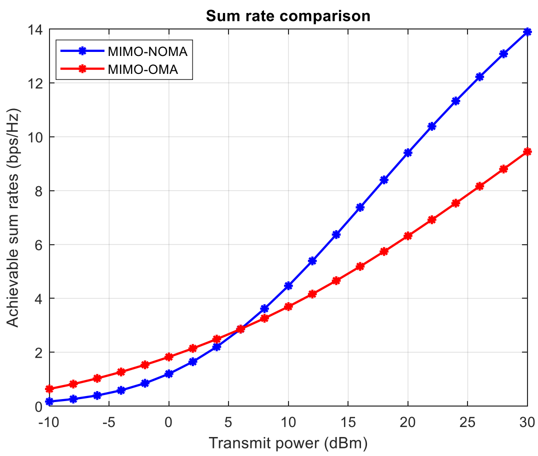

Figure 10. The capacity of user rates performance 4-user case.

It can be observed that at low SNR, OMA performs slightly better than NOMA. This is because, NOMA users suffer from interference, while OMA users do not experience any such interference. At high SNR, however, NOMA outperforms OMA by offering high capacity. In the outage probability calculation. target rate for each user is set. In this study, for user 1, we set the target rate as 1 Mbps/Hz and for user 2, we set the target rate as 2 Mbps/Hz. With Counting the number of times that user rates are below the target rates and then the average is taken. The outage probabilities as a function of transmit power are plotted as shown in Figure 11 to Figure 13. Figure 14 shows the obtained EE-SE curves for this setup with applying the cases of two-user, three-user, and four-user, the. It is seen that NOMA achieves higher EE and SE than OMA system.

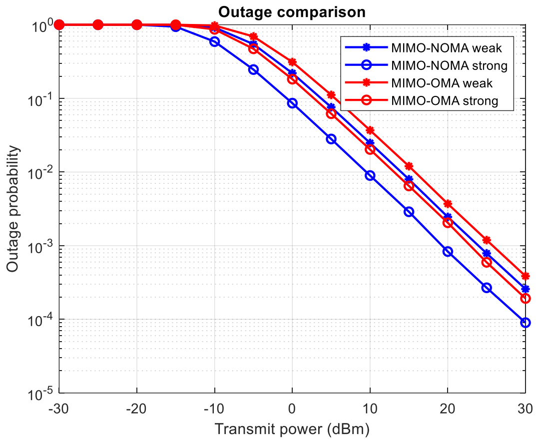

Figure 11. The outage probabilities performance2-user case.

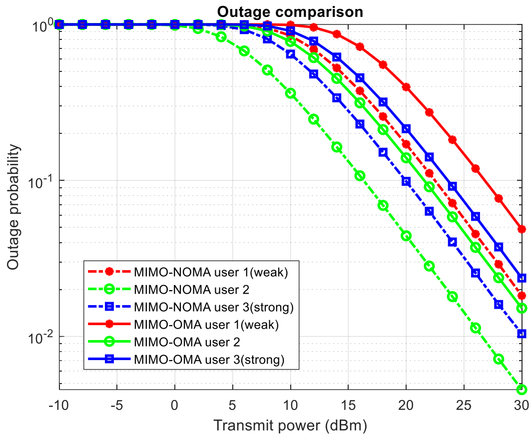

Figure 12. The outage probabilities performance 3-user case.

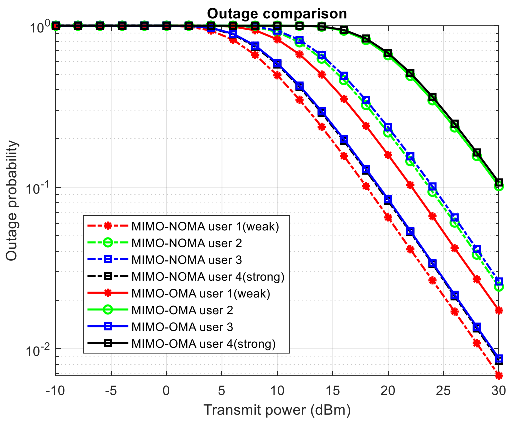

Figure 13. The outage probabilities performance 4-user case.

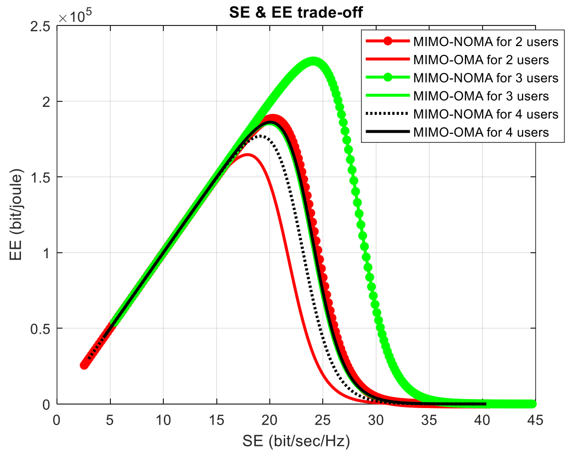

Figure 14. EE-SE trade-off curves for NOMA OMA.

MIMO NOMA for the first user has the best performance followed by the OMA outage probabilities of the two users then MIMO NOMA better outage probabilities compared to MIMO OMA. Applying Spectral Efficiency and Energy Efficiency Equations, the comparison is done in terms the EE and SE of NOMA with OMA. The system bandwidth is taken as $W = 5$ MHz. The channel gains for UE_1 and UE_2 are, respectively, taken as $g_1^2 = -120$dB and $g_2^2 = -140$dB. Noise density N_0 is taken as −150 dBW/ Hz. It has been assumed that the static power consumption at the BS is $P_{static} = 100W$.

7. Conclusion

This study presents the performance of SIC in downlink MIMO-NOMA, which is estimated by measuring the bit error rate, with different number of users. There are three scenarios according to number of users: 2-user, 3-user, and 4-user. Where the results clearly show that the bit error rate is decreased as SNR increased until reaches to zero. The study also presents the fundamentals of MIMO-

NOMA and demonstrated its superior performance over conventional MIMO-OMA in terms of sum capacity, energy efficiency and spectral efficiency.

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