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INVESTIGATING THE ROLE OF MULTI-USER ACCESS IN 5G NETWORK

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Abstract- Non orthogonal multiple access (NOMA) technology has been proposed as a means to meet the requirements of the 5G. It may improve spectrum efficiency by nudging users into cooperative usage of radio resources and increasing the variety of non-orthogonal resources at their disposal. However, the lack of orthogonally in these technologies results in signal interference between users, which may be lessened by using sophisticated, highly complex receivers. Power Domain Non-Orthogonal Multiple Access (PD NOMA) and Multi-User Sharing Access (MUSA) schemes are two examples of NOMA technologies that improve system throughput, increase the number of users sharing a single radio resource, and gain greater flexibility in the reuse of system resources. In order to enhance decoding performance, these techniques may be applied to downlink and uplink systems. The simulation results demonstrated that, in terms of feasible minimum rates per user and overall power usage, our suggested method beat the Orthogonal Multiple Access (OMA) benchmark. Additionally, the suggested technique outperformed the traditional MUSA scheme in terms of bit error rate performance.

Keywords: OMA, MUSA, Minimum Mean Squared Error MMSE, PD NOMA, Non-Orthogonal Multiple Access.

1. INTRODUCTION

The 1980s saw the beginning of extensive study and development of cellular systems in response to the Maxwell experiments. The first generation (1G) of cellular networks evolved when Heinrich Hertz successfully produced and detected these electromagnetic waves, later referred to as radio waves. Clark Maxwell discovered electromagnetic waves, which may travel close to the speed of light. With the widespread use of these systems, new generations appeared about every ten years until the fifth generation emerged [1].

In the 1980s, people used cellular communication networks to make analog phone calls. This was followed by 2G in the 1990s, 3G at the turn of the century, and 4G in 2010. As a consequence of rapid technological development in a wide range of sectors, a plethora of novel applications like IoT apps have emerged.

The development of the fifth generation of cellular communication systems began with the search for innovative technologies or the refinement of those already in use in order to fulfill new requirements and improve upon existing performance standards like spectral efficiency, user density, and time-response latency [2].

"Several access" refers to the underlying technology that allows the wireless base station to manage and offer services to multiple clients or devices at once. Orthogonal Multiple Access (OMA) took advantage of the orthogonal resource components of older cellular networks to provide user access to the network. In an OFDMA system, each user operates on a separate carrier frequency, and one or even more orthogonal resource components are allocated to them. For future generations of cellular communications, the (NOMA) schemes are seen as a feasible radio access technique for increasing performance, particularly in the face of restricted radio resources like the radio spectrum [3].

OMA solutions have shown promising performance outcomes for legacy applications and services. It's also easier to use than NOMA technology, which is a major differentiator. Due to necessities like the Internet of Things and the scarcity of orthogonal resources, OMA technologies have lost the capacity to address the significantly rising demands of wireless communication networks [4]. The traditional power domain NOMA technique decreases the chance of an outage and increases the possible rate, in comparison to ordinary OMA systems. Not only do cooperative NOMA systems excel in these areas, but they also outperform cooperative OMA structures in terms of outages as well as rate performance. Another perk is that PD NOMA is compatible with state-of-the-art methods like massive MIMO transmission [5].

Scrambling, interleaving, and short and long spreading sequences are a few examples of NOMA uplink technology. The PDMA and SCMA techniques utilize multi-dimensional constellations based on codebooks, while the MUSA system uses short spreading sequences [6]. It has been proposed that 5G employ non-orthogonal multiple access to improve performance (NOMA). It is probably going to be used in the next generation due to its compatibility with emerging technology.

The challenges include interference management, high computational complexity, practical implementation, and error propagation. PD-NOMA and OFDMA systems have the feature of compatibility with OMA technologies and advanced technologies proposed for fifth-generation systems, such as massive MIMO [7].

When working with a limited amount of available radio spectrum, NOMA may be used to maximize spectral efficiency [8]. In terms of bit error rate for uplink transmission at low UOL, MUSA performed better than SCMA and PDMA techniques; however, as user overload increased, MUSA performed better than SCMA. Communicating with many people at once is the goal of the MUSA method, which employs complex yet quick sequences. The transmitted symbols from all users at the same resource element are spread by orthogonal functions with a generalized frequency division multiplexing waveform. It can support high user overload in the uplink transmissions, so it is a promising technology in many applications in 5G and beyond [9].

NOMA schemes are proposed to improve SE through users' sharing of radio resources and increasing the degree of freedom in the number of non-orthogonal resources. However, these technologies suffer from interference due to the absence of orthogonally, which can be reduced by using advanced receivers of high complexity [10]. From [11], we looked at the principles of NOMA technology and the advantages it. The data of PD NOMA out performs OFDMA is the term of total user rate, and that SCMA out performs the LTE system.

PD-NOMA outperforms exhaustive and random user pairing algorithms in terms of energy efficiency and spectral efficiency [12]. A previous study used specific complex spreading sequences in the system without evaluating the impact of these sequences. Both technologies use the same SIC receiver, where the user overload parameter is 150% and the user locations are fixed in an AWGN channel [13]. In [14], PD-NOMA was implemented in the MUSA system to improve error probability performance, but the previous study used complex spreading sequences without considering quality of service requirements.

In [15], MUSA scheme reduces error probability of device discovery in D2D network communications. MUSA scheme can support high user overload, but UOL increases, making it unsuitable for some applications [16]. MUSA does better than SCMA and OFDMA in AWGN channels with a high signal-to-noise ratio, but it has a higher bit error rate and a higher packet error rate than similar systems. [17]. Based on MUSA [18] showed a unique NOMA technique for mMTC and the Internet of Things (IoT). Using short, complicated sequences, the MUSA approach is used by a large number of users to make the system work well in terms of low latency, high user load, and low bit error rate. When a generalized orthogonal frequency-division multiplexing waveform is used, orthogonal functions are used to spread out the signals sent by all users within a single resource element.

In this study, we enhance the NOMA uplink-downlink transmission system Multi-user Shared Access' (MUSA) performance. The Power Domain NOMA (PD-NOMA) technique is used to assess MUSA's performance for a significant user overload scenario in the NOMA uplink.

2. SYSTEM MODEL

Consider a scenario of uplink within a single cell, including a single base station, to serve N users sharing L elements of a radio resource block (frequency and/or time resources). We assume that the added resources created by applying MUSA technology, represented by complex spreading sequences, are allocated in a single, unique manner without the collision that occurs when a spreading sequence itself is chosen by more than one user. The MUSA uplink system consists of a group of transmitters and one receiver, as shown in Figure 1.

In a wireless communication system, the Power Domain method of multiple access, often known as NOMA, is a multiple access methodology that enables numerous users to utilize the same frequency resource. It is predicated on the concept of allotting varied quantities of electricity to each user in order to offer different users with varying degrees of service at any one time. This is accomplished by assigning a greater quantity of power to users who have a higher channel gain and a smaller quantity of power to users who have a lower channel gain.

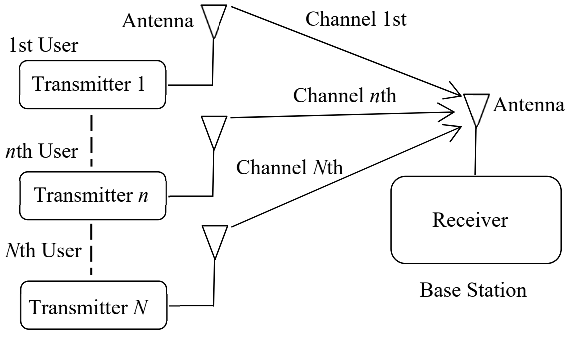

Figure 1. System model

Figure 1 shows each transmitter modulates the digital data to be transmitted and then spreads it on the available radio resources using short spreading sequences. In practice, the uplink signals are overlapped at the base station receiver, which eliminates interference between these signals sequentially using the SIC technique and estimates the data for each user. But for the design and performance evaluation, the superposition code is used to model and simulate this overlap [19-22].

A "channel" that is characterized by fading and additive white Gaussian noise is then used to transmit the created signal. In this research, it is assumed that both the transmitter and the receiver are aware of the features of the channel. It is also thought that both the transmitter and the receiver at the base station will utilize a single antenna.

3. RESULTS AND DISCUSSION

MATLAB environment is used to draw findings and assess how well the suggested system works. The intricate spreading patterns. Random numbers that match the quantity of users and duration of each sequence may be used to create complex spreading sequences. Nevertheless, in order to conduct the simulation at a specific set of sequences, a total of twenty complicated spreading sequences of varying durations were chosen. Such that a subset of the spreading sequences matrix is chosen to accommodate the needed number of users [20].

The simulation parameters in Table 1 indicate that the user overload in this scenario may approach 500%. Assuming that our system model uses the Rayleigh flat fading channel and that the transmitter and receiver both know the channel coefficients.

Table 1. Simulation coefficients

Description	Symbol	Values
Length of complex spreading sequence	L	4
Number of users	N	L: L/2: 5L
Noise power (dBm)	σ^2	-144
Maximum number of iterations for Algorithm 1 and Algorithm 2	t_1, t_2	1,2, 3,…,20
Required minimum rate values (b/s/Hz)	$R_{\min}$	0.01:0.01: 2
Number of transmitted symbols	N_d	1000

The findings that were retrieved show how the hybrid NOMA system performed in comparison to the OMA benchmark system under the following:

- First Case: System simulation for the matrix of the original spreading sequences partially selected from the used matrix in reference [20], so that all users transmit with the maximum available power $P_{\max}$ calculated by Equation (1):

$$P_{\max} = \max_{n\in\{1,\ldots,N\}} \{P_{n.\min}^{OMA}\} \tag{1}$$

- Second Case: System simulation for matrix of spreading sequences generated by applying Algorithm 1, so that all users transmit with the maximum available power $P_{\max}$ calculated by the Equation (1).
- Third Case: System simulation for the original matrix of spreading sequences partially selected from the matrix [20], so that users transmit with the powers resulted from Algorithm 2 implementation.
- Fourth Case: System simulation for the matrix of spreading sequences generated by applying Algorithm 1, so that users transmit with the powers results from Algorithm 2 implementation. The system simulation involves using a matrix of spreading sequences partially selected [20], or generated by applying Algorithm 1.

Algorithm 1. System simulation for matrix of spreading sequences

```
Input: Spreading sequences matrix S, Allocated powers $\sqrt{P}$,
  Channel coefficients matrix $h=[h_1\ldots, h_n\ldots, h_N\ldots]$
  Number of user N, Noise power $\sigma^2$, Length of sequences L
  Maximum number of iterations $t_1$.
Output: Near optimal sequences matrix $S_{opt}$.
Steps:
Compute $\gamma_n^0$ for each user and find detection order $K^{(0)}$ by applying Algorithm 1.
    $S_{opt} \leftarrow S$
    $\gamma_{\min}^{(0)} \leftarrow \min_{n\in\{1,\ldots,N\}} \{\gamma_n^{(0)}\}$
Reorder the columns of matrix according to $K^{(0)}$
    $S^{(0)} \leftarrow S(:,K^{(0)})$
for t= 1 to t= $t_1$ Repeat
    Compute $\gamma_n^{(1)}$ for each user and find detection order $K^{(1)}$
    by applying Algorithm 1 for new sequences matrix $S^{(0)}$
    $\gamma_{\min}^{(1)} \leftarrow \min_{n\in\{1,\ldots,N\}} \{\gamma_n^{(1)}\}$
    If $\gamma_{\min}^{(1)} > \gamma_{\min}^{(0)}$ Then
        $S_{opt} \leftarrow S^{(0)}$
        $\gamma_{\min}^{(0)} > \gamma_{\min}^{(1)}$
    End if.
    $S^{(0)} \leftarrow S(:,K^{(1)})$
end for
```

The users transmit with the maximum available power $P_{\max}$ or the powers results from Algorithm 2 implementation, for four cases. Achievable minimum rates for four cases and in the OMA, benchmark is incremented, when the required minimum rate is grown, as shown in Figure 4, where the user's number is N=6 and the maximum number of iterations for Algorithm 1 and Algorithm 2, t_1= t_2= 10.

Algorithm 2. System simulation for original matrix of spreading sequences partially selected from the matrix

```
Input: Spreading sequences matrix S, Length of sequences L, Noise power $\sigma^2$,
  Channel coefficients matrix $h=[h_1\ldots,h_n\ldots,h_N\ldots]$, $\varepsilon$ from
    $\varepsilon = \left|\max\{R_n^{OMA}\}_{n=1}^{N} - \min\{R_n^{OMA}\}_{n=1}^{N}\right|$
  Number of users N, Maximum power $\sqrt{P_{\max}}$ from
    $P_{\max} = \max_{n\in\{1,\ldots,N\}} \{P_{n.\min}^{OMA}\}$
  Maximum number of iterations $t_2$, The required minimum rate $R_{\min}$.
Output: Near optimal power allocation $\sqrt{P_{opt}}$.
Steps:
Set any power in $\sqrt{P} = [\sqrt{P_1},\ldots,\sqrt{P_n},\ldots,\sqrt{P_N}]$ to maximum.
    $\sqrt{P_n} \leftarrow \sqrt{P_{man}}$ for any $n\in\{1,\ldots,N\}$.
    $\sqrt{P_{opt}} \leftarrow \sqrt{P}$, $t \leftarrow 0$
While $t \le t_2$ Repeat
    $t \leftarrow t+1$
    Compute $\gamma_n^{(0)}$ for each user by applying Algorithm 1.
    Calculate $R_n^{(0)}$ for each user at $\gamma_n^{(0)}$.
    Find j using
        $j = \{i \,|\, \gamma_i(P) = \min_{n\in\{1,\ldots,N\}} \{\gamma_n(P)\}, i\in\{1,\ldots,N\}\}$ at $\gamma_n^{(0)}$
    Calculate
        $\sqrt{P} = [\sqrt{P_1},\ldots,\sqrt{P_{j-1}},\sqrt{P_j},\sqrt{P_{j+1}},\ldots,\sqrt{P_N}]$
    Using
        $P_m = ((\prod_{n=1}^{N}(1+\gamma_n(P)))^{\frac{1}{N}} - 1)/P_m, m \ne j$ at $\gamma_n^{(0)}$
        if $\sqrt{P_n} > \sqrt{P_{\max}}$ Then
            $\sqrt{P_n} \leftarrow \sqrt{P_{\max}}$
        end if
    $\sqrt{P_{opt}} \leftarrow \sqrt{P}$
    Calculate $\varepsilon_0 = \left|\max\{R_n^{(0)}\} - \min\{R_n^{(0)}\}\right|$
    if $\varepsilon_0 \le \varepsilon$ Then stop.
    else continue
    end if
end while
```

But this increase becomes very small in the first and second cases compared to the third and fourth cases and even in the OMA benchmark. Under the OMA benchmark, the minimal feasible rate is the same as the minimum necessary rate. This is due to the fact that the plan was developed with the intention of maximizing the amount of available electricity to meet the target rate. It is noted that the hybrid NOMA scheme in its four cases achieves an achievable minimum rate better than the OMA benchmark. Based on the data shown in Figure 2, the hybrid NOMA method works best in the fourth example, where the lowest feasible rate is equal to 6.53 b/s/Hz at $R_{\min}$= 1 b/s/Hz, which means an increment of 5.53b/s/Hz compared to the OMA benchmark (gain is 653%). While in the third case a gain of 614% can be achieved, in the second of 419% and the first of 318%, compared to the OMA benchmark at the same the required minimum rate $R_{\min}$=1 b/s/Hz. Figure 3 shows the samples of achievable minimum rate for 6 users where, $R_{\min}$= 1 b/s/Hz and t_1= t_2= 10.

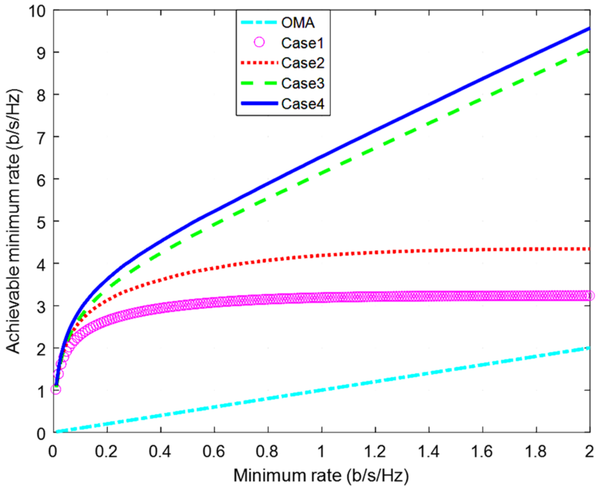

Figure 2. Achievable minimum rate at various required minimum rate values for N= 6 and t_1 = t_2 = 10

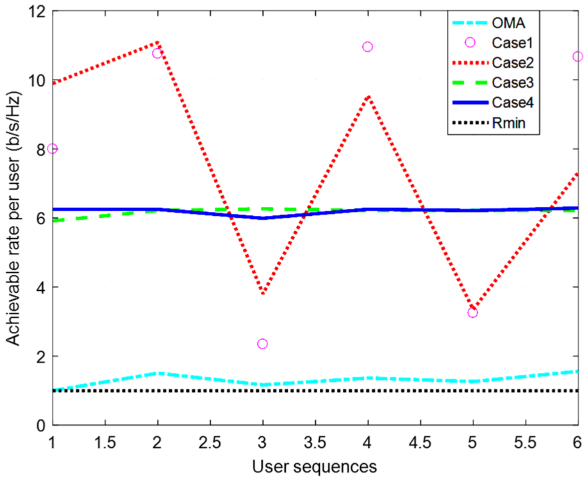

Figure 3. Samples of achievable minimum rate for 6 users where $R_{\min}$= 1 b/s/Hz and t_1 = t_2 = 10

Figure 4 shows the powers allocated to each user in the four cases of the hybrid NOMA scheme and in the OMA benchmark, which correspond to the results shown in Figure 3. In Figure 5, the hybrid NOMA scheme in the first case achieves a fixed gain of 318.6% compared to the OMA benchmark. While, the hybrid NOMA scheme in the second, third and fourth cases achieve gains of 356.9%, 483.3% and 518.2%, respectively, for one iteration t_1= t_2= 10.

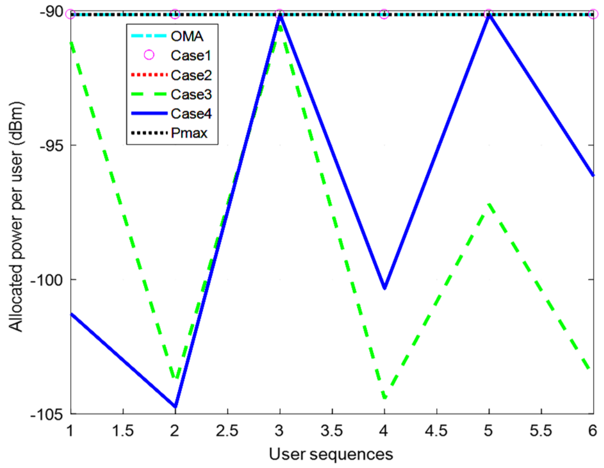

Figure 4. Samples of allocated powers for 6 users where $R_{\min}$= 1 b/s/Hz and t_1 = t_2 = 10

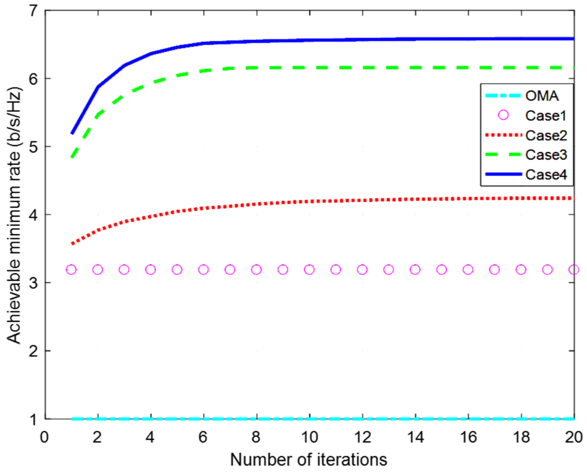

Figure 5. Achievable minimum rate at various numbers of iterations where, N= 6 and $R_{\min}$= 1 b/s/Hz

The lowest rate that the hybrid NOMA system can achieve lowers as user congestion rises. In all four circumstances, the lowest achievable throughput will decrease as the system's user base grows. As shown in Figure 6, where, $R_{\min}$= 1 b/s/Hz and t_1 = t_2 = 10. The hybrid NOMA scheme in the third and fourth cases performs better than in the first and second cases as the performance collapses faster in these two cases to the point that the required minimum rate is not able to be met. For user overloading = 400% (corresponding to the number of users N= 6 and $R_{\min}$= 1 b/s/Hz, it is found the achievable minimum rate less than 0.9 b/s/Hz in the first and second cases. While, it exceeds 2 b/s/Hz in the third and fourth cases. Figure 6 illustrates how the transmission powers in the OMA benchmark are established such that the necessary minimum rate is fulfilled for each user and that the minimum rate does not vary when more users are added to the system.

Figures 2-6 depicts simulation results demonstrating the efficacy of the suggested algorithms to increase performance in terms of minimum rate with various percentages and the potential of increasing the feasible minimum rate with various percentages by more than 500% in some circumstances.

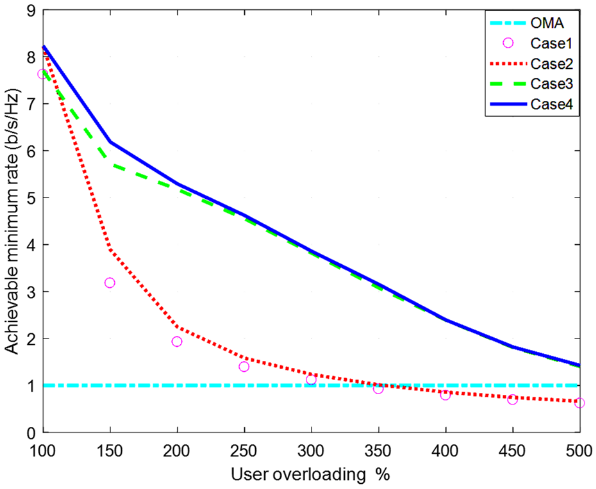

Figure 6. Achievable minimum rate at various user overloading values where, $R_{\min}$= 1 b/s/Hz and $t_1 = t_2 = 10$

The hybrid NOMA scheme's suggested algorithms are beneficial in more ways than only enhancing minimum rate performance. As demonstrated in Figure 7, where the maximum power and the total power to noise power ratio rise with the growing needed minimum rate, it also helps to lower the overall power spent in the system. Also, total power to noise power ratio in the OMA benchmark, the first and second instances is 39.88 dB, while in the third and fourth cases, it is 34.67 dB and 35.39 dB, respectively. In other words, at these numbers, it is feasible to reduce overall power consumption.

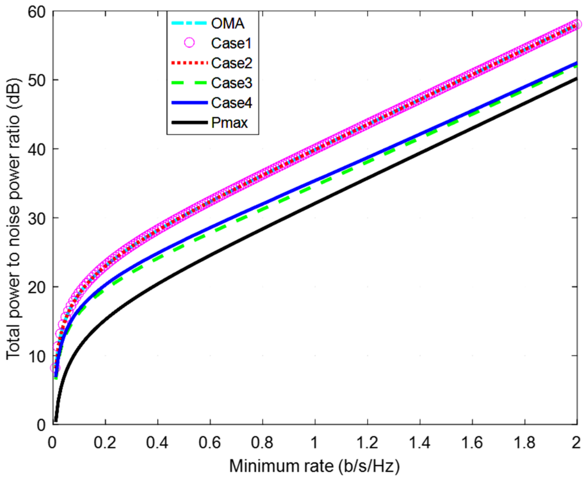

Figure 7. Total power to noise power ratio at required minimum rate values where, N= 6 and t_1= t_2= 10

The maximum number of iterations have an impact on the total power to noise power ratio in the third and fourth instances, as illustrated in Figure 8, before being practically constant after the sixth iteration. The total power to noise power ratio is thus 37.77 dB in the third instance and 37.86 dB in the fourth, equating to total power savings in the third and fourth cases when compared to total power used at. Figure 8 shows that, despite the employment of the second iterative technique, the performance of the second example remains consistent across the maximum number of iterations. This is due to the fact that, like in the first scenario and the OMA benchmark, the power allotted to all users is at its maximum in this instance.

It is normal for the total power to noise power ratio to increase as the user overloading increases as shown in Figure 11, where $R_{\min}$= 1 b/s/Hz and t_1= t_2= 10. This is because of the increasing in the number of transmitting devices. But this percentage of the third and fourth is lower than the one of other cases and the OMA benchmark. For example, when user overloading = 400%, it can be saved 60% from the consumed power where the total power to noise power ratio is (77.32 dB) in the third and fourth cases and (81.28 dB) in the rest of the schemes.

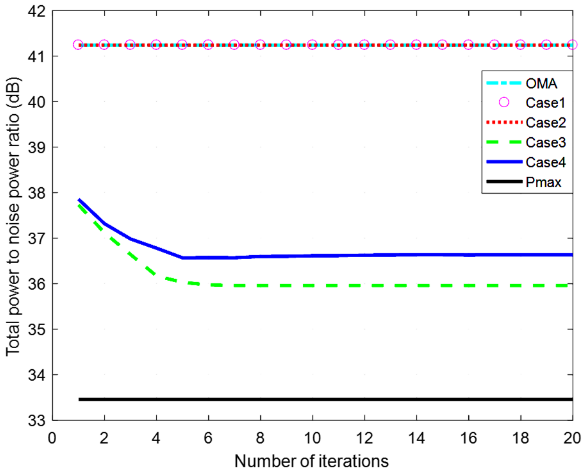

Figure 8. Total power to noise power ratio at various numbers of iterations where, N= 6 and $R_{\min}$= 1 b/s/Hz

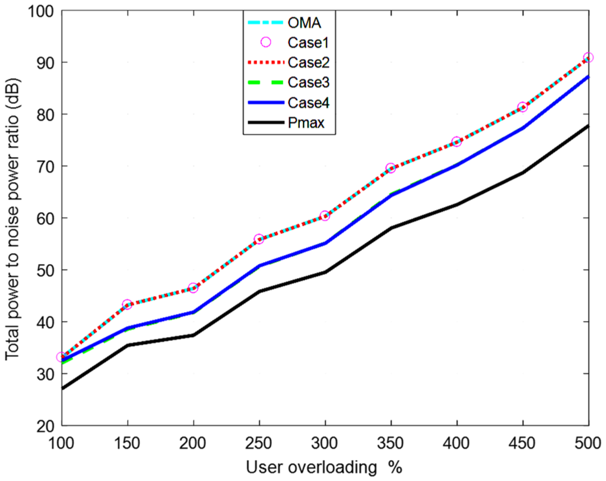

Figure 9. Total power to noise power ratio at various user overloading values where, $R_{\min}$= 1 b/s/Hz and $t_1 = t_2 = 10$

The suggested methods for the hybrid NOMA system model aid in lowering *BER*, as shown in Figure 9. While it is in the first and second circumstances, the theoretical error probability is reduced in the third and fourth cases. Figure 10 indicates that the error probability decreases as the minimal signal-to-interference and noise ratio increases, which is the major objective of this problem (P1). Figure 2 also demonstrates that this is the reason why the minimum rate rises.

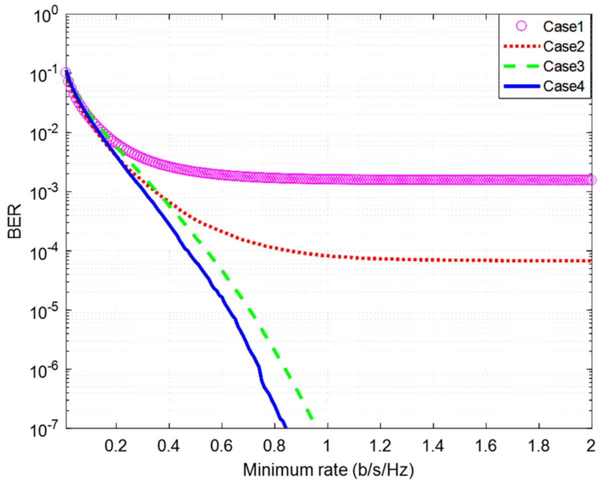

Figure 10. BER at required minimum rate values where, N= 6 and t_1= t_2= 10

In addition, the *BER* in the system decreases as the total power to noise power ratio increases, as shown in Figure 11 where, t_1= t_2= 10 and N= 6. But the performance of the error probability is improved in the third and fourth cases than it was in the first and even the second cases. When the total power to noise power ratio is 25 dB, the error is *BER*= ~10^{-3} in the first and second cases. While, it improves in the remaining two cases to become *BER*= ~10^{-4}.

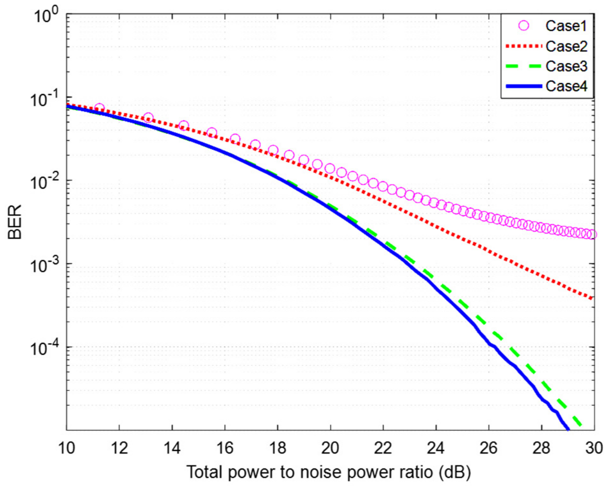

Figure 11. BER versus total power to noise power ratios where N= 6 and t_1 = t_2 =10

As can be seen in Figure 12, the risk of a mistake decreases as the maximum number of repetitions increases. Nonetheless, case four provides the most optimal results. The performance becomes almost constant after the sixth iteration in the second and third cases, but the error probability becomes a hundred times smaller when the number of iterations increases from 1 to more than 6 in the third and fourth cases.

For the comparison between the four cases, it is noticed that the error probability decreases by a small amount in the second case compared with the first. While it is a hundred times less in the third and fourth cases than it was in the first. Figure 13 illustrates the impact of high user overloading on *BER* performance, showing that for and the error probability rises as user overloading increases. However, the third and fourth examples suggested iterative techniques helped to lower the error probability, particularly when for instance, the system *BER* changes in the first and second situations to instead. But when it did, compared to the first and second situations, the mistake probability was 1,000 times lower.

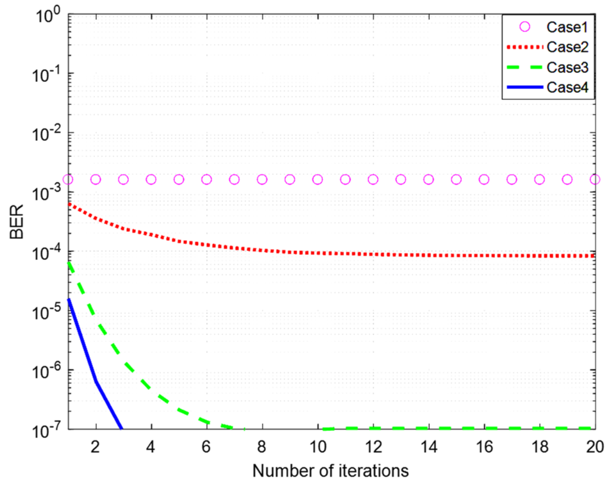

Figure 12. BER at various numbers of iterations where, N= 6 and $R_{\min}$= 1 b/s/Hz

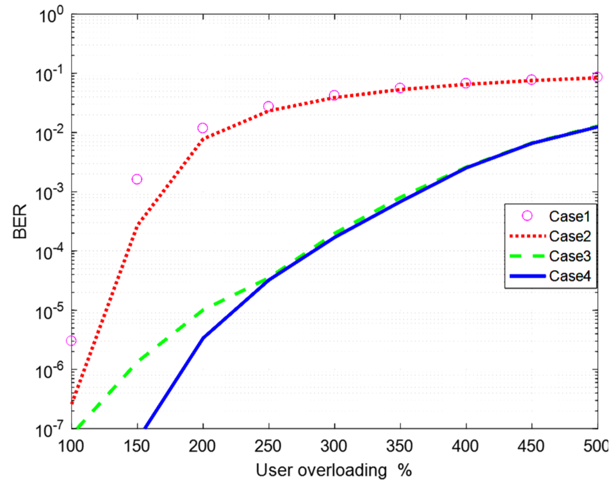

Figure 13. BER at various user overloading values where $R_{\min}$= 1 b/s/Hz and t_1 = t_2 = 10

4. CONCLUSIONS

The main idea and advantages of NOMA approaches were presented in this research. The major emphasis was on power-efficient approaches that boosted system throughput and increased the number of users sharing a single radio resource. In order to enhance decoding performance, both PD NOMAs and MUSA algorithms were employed in both downlink and uplink systems based on the MMSE-SIC receiver. Performance, including bit rate, fairness, and error probability, was impacted by the signal-to-interference and noise ratios. The OMA system was put out as a standard for determining the maximum power that corresponds to the necessary minimum rate.

The simulation results showed that, in terms of feasible minimum rates per user and overall power usage, our suggested method beats the OMA benchmark. In practice, the effects of incomplete consecutive interference cancellation were disregarded. It was investigated whether or not SCMA might be used to increase uplink performance in light of the results obtained by hybrid NOMA systems. Auto- and cross-correlation features of intricate spreading sequences in the MUSA scheme, and power distribution in the PD NOMA.

NOMENCLATURES

1. Acronyms

NOMA	Non-Orthogonal Multiple Access
PD NOMA	Power Doman Non-Orthogonal Multiple Access
MUSA	Multi User Sharing Access
MMSE	Minimum Mean Squared Error
OMA	Orthogonal Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
SC	Superposition Coding
IC	Interface Cancellation

2. Symbols / Parameters

L: Length of complex spreading sequence
N: Number of users
σ^2: Noise power (dBm)
t_1, t_2: Maximum number of iterations for Algorithms 1, 2
$R_{\min}$: Required minimum rate values (b/s/Hz)
N_d: Number of transmitted symbols

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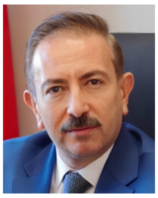

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