Cihan University-Erbil Scientific Journal (CUESJ)

REVIEW ARTICLE

Dynamic Power Allocation for Downlink NOMA

Yazen S. Almashhadani, Ghassan A. Qasmarrogy

Department of Communication and Computer Engineering, Cihan University-Erbil, Kurdistan Region, Iraq

ABSTRACT

Dynamic power distribution for connected non-orthogonal multiple access (NOMA) is an important research area in wireless communication systems. This study focuses on the implementation and evaluation of dynamic power distribution strategies in the context of NOMA downlink. We compare the performance of dynamic power distribution and power distribution schemes to evaluate their impact on system output, interference control, and overall efficiency. Through extensive simulation and analysis using MATLAB, this article presents the comparison between dynamic power distribution and fixed power distribution, and the advantages of dynamic power distribution in adaptive to change the channel conditions and the user's need to improve the system performance. Our results show that data rates and non-loss can provide an important insight into the benefits of dynamic power distribution in NOMA downlink systems and emphasize the importance of adaptive power management techniques in improve wireless communication networks.

Keywords: Non-orthogonal multiple access, Rayleigh channel, user pairing, power allocation, outage probability

INTRODUCTION

The emergence of dynamic power allocation (DPA) for downlink non-orthogonal multiple access (NOMA) as a key area in the field of wireless communication systems is aimed at increasing both spectral efficiency and system performance.[1]

In addition, NOMA is capable of allowing several users to share time-frequency resources by employing power domain multiplexing resulting in increased spectral efficiency and better user experience. In this scenario, downlink where a base station (BS) communicates with several users simultaneously, optimization of system performance through DPA becomes important as it allocates levels of power depending on channel conditions, user demands, and interference management methods. This introduction lays the foundation for investigating the significance of DPA in downlink NOMA systems and how they enhance throughput, system capacity, and overall network performance.[2] The NOMA with multiple users as shown in Figure 1.

The aim of this study focuses on examining the efficiency of DPA strategies in the framework of downlink NOMA using the software MATLAB. The notion behind DPA is that it alters the assigned powers to users as per channel conditions and QoS requirements for a purpose of enhancing system throughput and minimizing interference.

On the other hand, some schemes allocate a fixed amount of power to each user in spite of channel variations. Our objective is to assess how adaptive power regimes enhance system's efficiency and general performance by comparing it with the performances of DPA approaches when compared against fixed power allocations (FPA). Through simulation-based analysis and performance evaluation, we seek to provide insights into the benefits of DPA in downlink NOMA systems and highlight the advantages of adaptive power management techniques in improving wireless communication networks. This study contributes to the ongoing research efforts in optimizing power allocation strategies for enhancing the performance of NOMA systems in practical scenarios. Through simulation-based analysis and performance evaluation, we seek to provide insights into the benefits of DPA in downlink NOMA systems and highlight the advantages of adaptive power management techniques in improving wireless communication networks. This study contributes to the ongoing research efforts in optimizing power allocation strategies for enhancing the performance of NOMA systems in practical scenarios.

While (OFDM) introduce a larger number of narrow band sub-channels which gives more transmit data rate,

Corresponding Author:
Yazen S. Almashhadani, Department of Communication and Computer Engineering, Cihan University-Erbil, Kurdistan Region, Iraq. E-mail: yazen.mahmood@cihanuniversity.edu.iq

Received: May 19, 2024

Accepted: June 14, 2024

Published: June 30, 2024

DOI:10.24086/cuesj.v8n1y2024.pp85-90

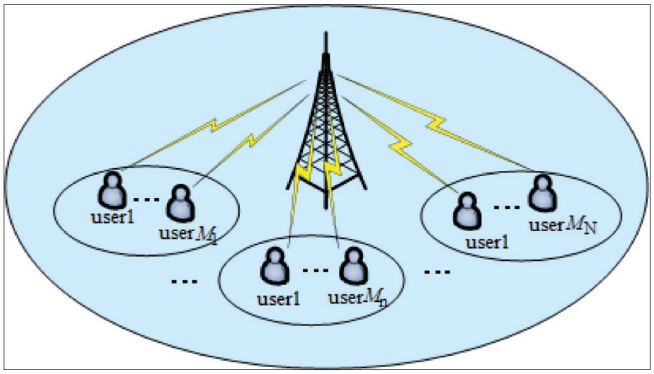

Figure 1: Non-orthogonal multiple access[2]

each sub-channel is orthogonal. They are narrow bands and closely spaced. Due to its capability to lever with multipath interference at the receiver OFDM is being used also, it splits the stream of high-rate data into a lower-rate stream that is transmitted simultaneously over a number of subcarriers.[3]

The rest of the paper will be organized as follows, in chapter two, related work will be showed and discussed, chapter three will investigate the system model, chapter four will show the analysis and result, and finally, in chapter, five a conclusion will be demonstrated.

RELATED WORK

Several studies have explored the application of DPA for downlink NOMA using MATLAB software. In a study by,[4] the authors proposed a DPA algorithm for downlink NOMA systems to maximize the sum rate of users while considering the quality-of-service requirements. The algorithm was implemented and evaluated using MATLAB simulations, demonstrating improved system performance compared to FPA schemes.

Similarly Liu *et al.*[5] investigated the impact of DPA in downlink NOMA systems using MATLAB. The authors developed a novel power allocation strategy that dynamically adjusts power levels based on channel conditions and user priorities. Through extensive simulations, they showed that DPA outperformed FPA in terms of system throughput and interference management.

Furthermore, Saeed and Sileh[6] conducted a comparative study between dynamic and FPA techniques in downlink NOMA systems using MATLAB. Their results indicated that DPA led to higher spectral efficiency and improved user fairness compared to FPA strategies.

Overall, these related works highlight the significance of DPA in optimizing the performance of downlink NOMA systems and emphasize the utility of MATLAB software for implementing and evaluating such algorithms.

SYSTEM MODEL

This paper focus on the downlink communication in NOMA. The scenario comprising a BS and M users each with corresponding channel condition denoted h_i where the channel coefficient linked from the BS to the i^{th} user, consider that U_1 is the first user, with channel h_1 being closest to the BS which deliberates the stronger user, the subsequent user U_2 is the second stronger user, and this pattern continuous accordingly. User U_M being the farthest/weaker follows this sequence.[7]

Figure 2 illustrates the system model of the downlink communication; we assume four users, that is, ($M = 4$) are distributed with different distances from the BS. Wireless paths assumed to undergo Rayleigh fading channel coefficients ordered as.[7]

$$|h_1|^2>|h_2|^2>|h_3|^2....|h_M|^2 \quad (1)$$

Denote the messages to be transmitted to the users as X_1, X_2... X_M. The BS utilizes superposition coding with these messages and sends the resultant NOMA signal into the channel, we can represent X_{NOMA} concisely as follows:

$$X_{NOMA} = \sqrt{P}\sum_{i=1}^{M}\sqrt{\pm_i}\ X_i \quad (2)$$

Here, P represents the total transmitted power, α_i signifies the power allocation coefficient for the i^{th} user.

The power allocation coefficients must be ordered as $\alpha_1 < \alpha_2 <....\alpha_M$, since the strong channel condition is assigned less power than the user with weak channel condition.

The received signal at user i is given by

$$y_{i\_NOMA} = X_{NOMA}h_i + \omega_i \quad (3)$$

Where ω_i is the additive white Gaussian Noise with zero mean and variance σ^2.

Given that U_M is allocated the highest power allocation; its intended message dominates the received signal. Consequently U_M engages in direct decoding, interpreting the signals intended for all other users as interference. U_{M-1} should directly decode U_M message, then perform successive interference cancelation (SIC) to remove it. After SIC, U_{M-1} becomes the dominating message signal. Thus, U_{M-1} can directly decode its message by regarding the message signals of all other remaining users as interference. We can apply a similar thought process to attain the decoding rule for the remaining users. In general, for any given user i, the signal to interference ratio (SINR) to decode his own signal is given by

$$\gamma_{i\_NOMA} = \frac{\alpha_i P\,|\,h_i\,|^2}{\sum_{j=i+1}^{M}\alpha_j P\,|\,h_j\,|^2 + \sigma^2} \quad (4)$$

The resultant rate for any intended user i based on Shannon's capacity formula[8] can be written as

$$R_{i\_NOMA} = B\log_2(1+\gamma_{i\_NOMA}) \quad (5)$$

Where B is the overall bandwidth. Therefore, the total capacity of downlink NOMA system with M users is given by the summation of the data rates of all users in the system as follows

$$R_{NOMA} = \sum_{i=1}^{M} R_{i\_NOMA} \quad (6)$$

On the other hand, orthogonal resource blocks use the orthogonal multiplexing approach. In orthogonal multiple

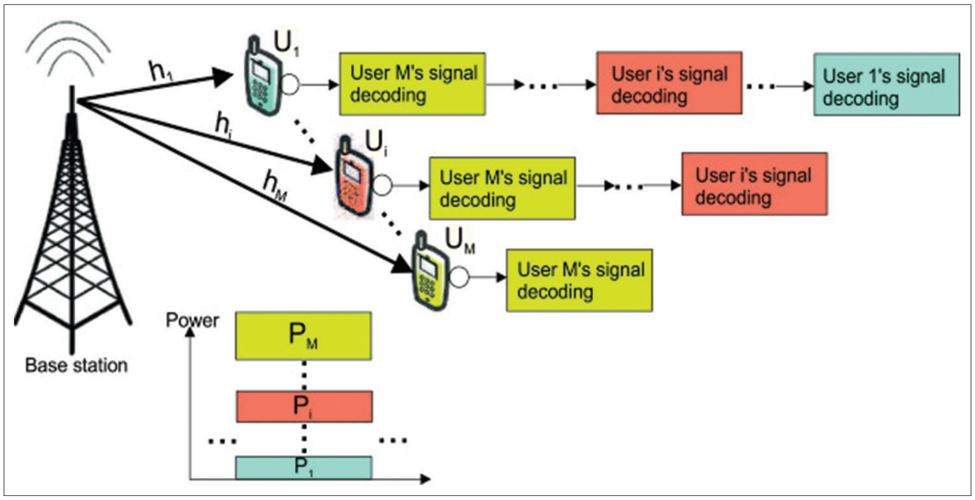

Figure 2: Downlink NOMA for M users

access (OMA) system, when the total bandwidth and power are shared among the users equally, therefore, the achieved data rates of users given as:

$$R_{i\_OMA} = \frac{B}{N}\log_2\left(1+\frac{P_i\,|\,h_i\,|^2}{\sigma^2}\right) \tag{7}$$

In OMA system, equally assigned user power is formulated as

$$P_i = 1/\mathrm{MP} \tag{8}$$

The total capacity of downlink OMA is calculated as

$$R_{OMA} = \sum_{i=1}^{M} R_{i\_OMA} \tag{9}$$

NOMA User Pairing

NOMA concurrently serves multiple users within the same frequency band. Although SIC technique is applied, the severe interference is noticed when the number of users is increases beyond the limit and yield a throughput drop of the overall system. The hybrid NOMA with OMA is utilized for interference degradation and diminished the complexity, of course this is tradeoff with the utilized spectrum.[9] Four users are considered in this work, so there are four possible user pairing can be chosen. The maximum channel gain difference between users is promises for better improvement of the date rate rather than other pairing distribution; hence, after rearrange, the four channel gains of the four users as $|h_1|^2 > |h_2|^2 > |h_3|^2 > |h_3|^2$, the stronger with the weaker (U_1 with U_4) is paired then the second stronger with the second weaker (U_2 with U_3) is paired. The SIC for every pair is applied as independent to the other pair.

The users in the first pair have to choose $\alpha_1 < \alpha_4$, the rates of the first and fourth user as follows:

$$R_1 = \frac{1}{2}\log_2\left(1+\frac{P\alpha_1\,|\,h_1\,|^2}{\sigma^2}\right) \tag{10}$$

After SIC

$$R_4 = \frac{1}{2}\log_2\left(1+\frac{P\alpha_4\,|\,h_4\,|^2}{P\alpha_1\,|\,h_4\,|^2+\sigma^2}\right) \tag{11}$$

The users in the second pair have to choose $\alpha_2 < \alpha_3$, the rates of the first and fourth user as follows:

$$R_2 = \frac{1}{2}\log_2\left(1+\frac{P\alpha_2\,|\,h_2\,|^2}{\sigma^2}\right) \tag{12}$$

After SIC

$$R_3 = \frac{1}{2}\log_2\left(1+\frac{P\alpha_3\,|\,h_3\,|^2}{P\alpha_2\,|\,h_3\,|^2+\sigma^2}\right) \tag{13}$$

Thus, the summation of the two pairs is calculated as follows:

$$R = R_1 + R_2 + R_3 + R_4 \tag{14}$$

Power Allocation

Power and resource allocation are performed in every pair of users sharing the same subcarrier.[10] For intended pair, the more power is allocated for far user, whereas the rest is allocated for the near user due to the channel coefficient of the far user is less than the channel coefficient of near user. The far user should meet its required target data rate. The different rates of far and near users will be summed for the corresponding transmit power. The power allocation strategies are aimed to maximize the overall system capacity measured in bits per second. There are two types of power allocation, the FPA and DPA based on channel condition. The former is constant (not change with the channel gain, the latter is providing the fair power allocation between users when the amount of power is adjusted according to the variation of channel gain by taking the feedback from the channel state information (CSI).[11]

Deriving the power allocation coefficients starts by denote R* as the target rate for far user choosing α_f and α_n such that $R_f \geq R^*$ is our goal.

We will set $R_f = R^*$.

$$\log_2\left(1+\frac{|\,h_f\,|^2\ P\alpha_f}{|\,h_f\,|^2\ P\alpha_n+\sigma^2}\right) = R^* \tag{15}$$

Now remove the for both sides

$$1+\frac{|h_f|^2\ P\alpha_f}{|h_f|^2\ P\alpha_n+\sigma^2}=2^{R^*} \tag{16}$$

$$\frac{|h_f|^2\ P\alpha_f}{|h_f|^2\ P\alpha_n+\sigma^2}=2^{R^*}-1 \tag{17}$$

Assume $\xi = 2^{R^*}-1$, ξ is the target SINR for the far user who has target rate R^*

$$\frac{|h_f|^2\ P\alpha_f}{|h_f|^2\ P\alpha_n+\sigma^2}=\xi \tag{18}$$

$$|h_f|^2\ P\alpha_f = \xi\ |h_f|^2\ P\alpha_n + \xi\sigma^2 \tag{19}$$

$$\alpha_f + \alpha_n = 1, \text{ so } \alpha_n = 1-\alpha_f \tag{20}$$

$$|h_f|^2\ P\alpha_f = \xi\ |h_f|^2\ P(1-\alpha_f) + \xi\sigma^2 \tag{21}$$

$$|h_f|^2\ P\alpha_f = \xi\ |h_f|^2\ P-\xi|h_f|^2\ P\alpha_f + \xi\sigma^2 \tag{22}$$

Collecting all the α_f from to the LHS

$$|h_f|^2\ P\alpha_f + \xi\ |h_f|^2\ P\alpha_f = \xi\ |h_f|^2\ P + \xi\sigma^2 \tag{23}$$

$$\alpha_f\ |h_f|^2\ P(1+\xi) = \xi\ (|h_f|^2\ P + \sigma^2) \tag{24}$$

$$\alpha_f = \frac{\xi(|h_f|^2\ P+\sigma^2)}{|h_f|^2\ P(1+\xi)} \tag{25}$$

Now will put a limit to α_f ensuring will not exceed 1

$$\alpha_f = \min(1, \frac{\xi\left(|h_f|^2\ P+\sigma^2\right)}{|h_f|^2\ P(1+\xi)}) \tag{26}$$

After utilizing the aforementioned formula to obtain αf, we can effortlessly determine α_f.

$$\alpha_n = 1-\alpha_f \tag{27}$$

Outage Probability

The outage probability is defined as the probability that the signal-to-noise ratio (SNR) of a channel fall below a certain target rate of data for evaluating any communication channel performance. NOMA allows all users to share the bandwidth equally, and hence, the data rate of each user necessity to be within the definite limits of channel capacity. The outage occurs when the data rate of a user or the sum rates of all users exceeds Shannon's corresponding data rate, which implies a data loss.[12] The general expression of the probability of outage is given as:

$$P_{Outage} = P\ (R < R^*) \tag{28}$$

Where; R is the calculated channel capacity and R^* is the target data rate of the user.

SIMULATION RESULTS

In this scenario, we assume four users with different distanced from the BS in the downlink NOMA mobile system, the channel is Rayleigh fading with 10,000 random generated paths and path exponent $n = 4$. These users are divided into two groups and two users per group since the user grouping scheme is used to maximize the system throughput and every group has its own subcarrier. Therefore, NOMA is applied on every two users considering a perfect SIC. The analysis of the system will mainly base on the assumption of two types of power allocation (FPA and DPA). The data rate per frequency and outage probability are simulated using MATLAB in this study.

Figure 3 shows the sum rate of two different pairing users' types of hybrid NOMA, the maximum channel difference pairing $\{(U_1, U_4), (U_2, U_3)\}$ gives a higher data rate compared with adjacent channel pairing users $\{(U_1, U_2), (U_3, U_4)\}$ in high SNR levels also the hybrid NOMA is better than OMA but the improvement is not significant, the performance of Single Carrier SC-NOMA is poor due to the big interference added as created from the signals to the users, especially when users are close together in terms of power levels.

In Figure 4. The comparison in sum rates is shown between the FPA and DPA for the four users. The users pairing of maximum channel gain difference is considered in each group; hence, every two users can be classified into far user and near user. The fixed power coefficient values of far and near users as $\alpha_f = 0.7$, $\alpha_n = 0.3$, respectively, nevertheless DPA adapt its coefficient values based on the channel gain value to optimize the allocation of transmit power between the near and far users to meet the specification, due to that DPA outperform FPA pointedly.

Figures 5 and 6 simulate the outage probability versus data rate. The simulation parameters of the system set constant transmit power as 30 dBm, noise power σ^2 of −114 dBm/Hz and the two users in each pair have the power allocation coefficient of $\alpha_f = 0.7$, $\alpha_n = 0.3$.

Figure 5 shows a comparison of the outage probability performances of FPA and DPA versus the target rate of the far user R^*. Far user and near user are located at the distances $d_1 = 1000$ m, $d_2 = 500$ m respectively, and compared their outage failure. We can notice that FPA exhibits significant underperformance with its outage probability reaching a saturation point of 1 beyond target rate of 2 bps/Hz, FPA not take in consideration the instantaneous CSI, in addition, disregards the target rate requirements. Therefore, FPA

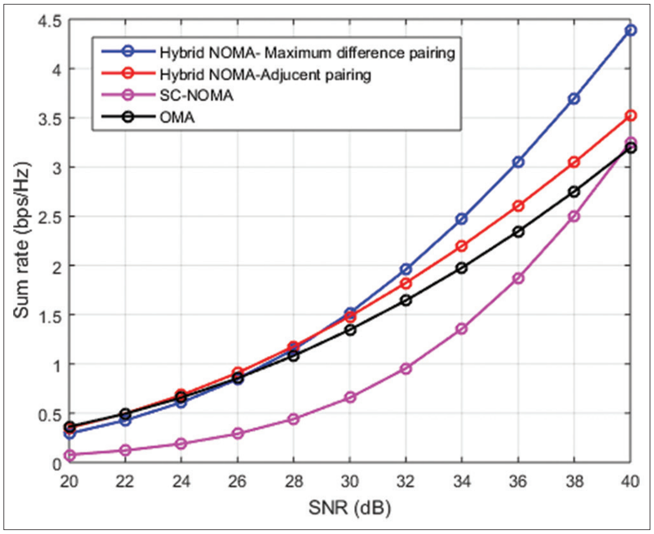

Figure 3: System sum rate under different multiplexing techniques

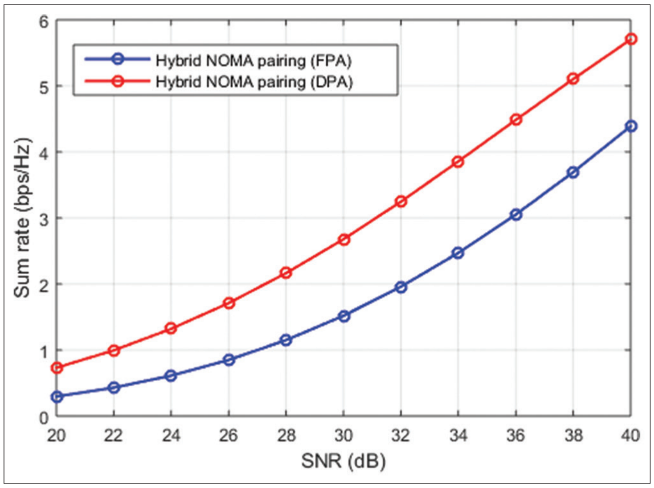

Figure 4: System sum rate of two user grouping method

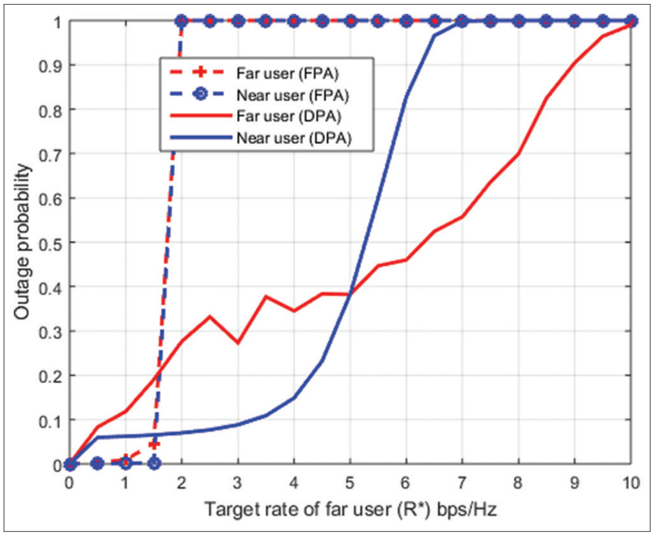

Figure 5: Outage probability of far and near user

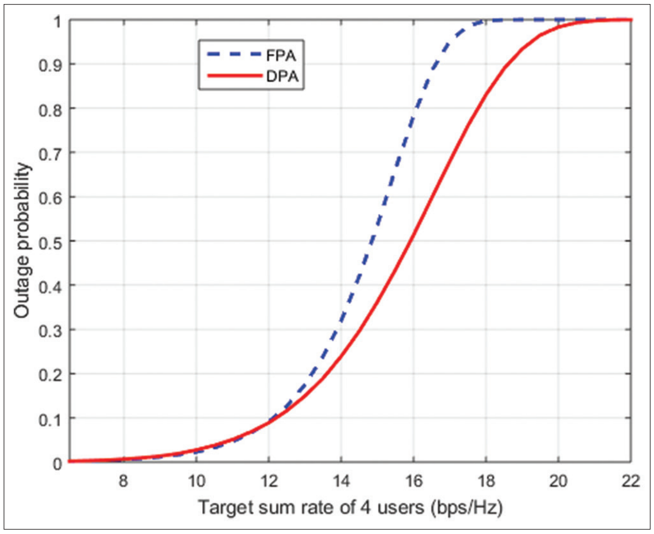

Figure 6: Outage probability of the system

although less complicated to implement, has low performance in general. The outage probability of near user behaves a sudden change from 4 to 7 bps/Hz values of R^*, then turn into always record outage at 7 bps/Hz and later.

The supposed system of four users (paired users) is evaluated and tested the outage probability for the distances of the users away from the BS by 400 m, 500 m, 800 m, and 100 m, respectively, as shown in Figure 6. FPA results in an outage after 16 bps/Hz, whereas DPA is better performed until fall in outage beyond 21 bps/Hz. Therefore, DPA has results in lower outage probability compared to FPA due to its ability to adapt to changing channel conditions and interference levels. DPA optimally allocates power resources to users based on their channel conditions, leading to improved system reliability and performance.

CONCLUSION

In this study, the analysis of NOMA was conducted using MATLAB software to evaluate data rate and outage probability in a multipath Rayleigh fading channel. By doing so, we were able to measure NOMA's performance in maximizing data rates and minimizing outage probabilities among multiple users that share the same resources. Our findings show that NOMA can greatly enhance spectral efficiency and system capacity over traditional OMA systems.

Furthermore, we accurately simulated and modeled outage probability and data rate through interactions amongst users, channels, and power allocations into a NOMA system using MATLAB hence giving us an insight on how different parameters affect data rates as well as outage probabilities thus enabling optimization of system performance.

In general, the users were classified into group of two according to the maximum channel gain difference then the power was distributed among the pair of users and it was obvious from the simulation results that the hybrid NOMA with DPA was better than fixed hybrid-NOMA for both outage probability and data rate. Furthermore, this system can be extended to more than four users which get the same achievements; it is also promising for future wireless communication systems of which some cases may involve critical considerations regarding spectral efficiency as well as resource utilization.

REFERENCES

1. Y. S. Mahmood and G. A. Qasmarrogy. Capacity analysis of multiple-input-multiple-output system over rayleigh and rician fading channel. *Cihan University-Erbil Scientific Journal*, vol. 3, no. 2, pp. 70-74, 2019.
2. G. A. H. QasMarrogy. IEEE 802.16 E&M systems bandwidth resource allocation performance investigation. *Journal of Engineering and Sustainable Development*, vol. 23, no. 4, pp. 155-169, 2019.
3. Y. S. Almashhadani, H. J. Alqaysi and G. A. QasMarrogy. Performance Analysis of OFDM with Different Cyclic Prefix Length. In: *Conference of Cihan University-Erbil on Communication Engineering and Computer Science*, p. 66, 2017.
4. H. Zhang, B. Wang, C. Jiang, K. Long, A. Nallanathan, V. C. Leung

and H. V. Poor. Energy efficient dynamic resource optimization in NOMA system. *IEEE Transactions on Wireless Communications*, vol. 17, no. 9, pp. 5671-5683, 2018.

5. P. Liu, Y. Li, W. Cheng, W. Zhang and X. Gao. Energy-efficient power allocation for millimeter wave beamspace MIMO-NOMA systems. *IEEE Access*, vol. 7, pp. 114582-114592, 2019.
6. S. H. Saeed and I. K. Sileh. Performance analysis of cooperative NOMA for different power allocation strategies. *Tikrit Journal of Engineering Sciences*, vol. 30, no. 4, pp. 102-117, 2023.
7. X. Li, Q. Wang, M. Liu, J. Li, H. Peng, M. J. Piran and L. Li. Cooperative wireless-powered NOMA relaying for B5G IoT networks with hardware impairments and channel estimation errors. *IEEE Internet of Things Journal*, vol. 8, no. 7, pp. 5453-5467, 2020.
8. M. Al-Imari, P. Xiao, M. A. Imran and R. Tafazolli. Uplink Non-orthogonal Multiple Access for 5G Wireless Networks. In: *2014 11th International Symposium on Wireless Communications Systems* (*ISWCS*). IEEE, pp. 781-785, 2014
9. O. Maraqa, A. S. Rajasekaran, S. Al-Ahmadi, H. Yanikomeroglu and S. M. Sait. A survey of rate-optimal power domain NOMA with enabling technologies of future wireless networks. *IEEE Communications Surveys and Tutorials*, vol. 22, no. 4, pp. 2192-2235, 2020.
10. G. A. H. QasMarrogy. IEEE 802.16 E&M systems bandwidth resource allocation performance investigation. *Journal of Engineering and Sustainable Development*, vol. 23, no. 4, pp. 155-169, 2019.
11. Z. Yang, Z. Ding, P. Fan and N. Al-Dhahir. The impact of power allocation on cooperative non-orthogonal multiple access networks with SWIPT. *IEEE Transactions on Wireless Communications*, vol. 16, no. 7, pp. 4332-4343, 2017.
12. L. Bhardwaj, R. K. Mishra and R. Shankar. Sum rate capacity of non-orthogonal multiple access scheme with optimal power allocation. *The Journal of Defense Modeling and Simulation*, vol. 19, no. 4, pp. 759-769, 2022.