Performance Analysis of NOMA Systems in Rayleigh and Rician Fading Channels

Bibekananda Panda
Department of EC
National Institute of Technology Rourkela
Odisha-769008, India
bibekananda_panda@nitrkl.ac.in

Poonam Singh
Department of EC
National Institute of Technology Rourkela
Odisha-769008, India
psingh@nitrkl.ac.in

***Abstract*—Non-Orthogonal Multiple Access (NOMA) is an effective innovation for fifth-generation and forthcoming wireless technology. NOMA aims to encounter the challenges of low latency, high accuracy, large availability, and peak performance. In this paper, the performance mechanisms of NOMA are discussed as compared to Orthogonal Multiple Access (OMA), and also for different user (far and near) scenarios. The techniques such as Heterogeneous Network (HetNet), Ultra-Reliable Low-Latency Communication (URLLC), and other 5G evolving technologies are highlighted for improved performance in the NOMA system. The simulation results are carried out to analyze the achievable capacity of OMA and NOMA, BER analysis, and sum-rate analysis of NOMA systems over Rayleigh and Rician fading channels. The simulation results reveal that the Rician fading channels have better performance than Rayleigh fading channels. This article also discusses potential research challenges as well as addressing current and future issues in NOMA.**

***Index Terms*—NOMA, Uplink Network, Downlink Network, Rayleigh fading channel, Rician fading channel**

I. Introduction

Non-Orthogonal Multiple Access (NOMA) has enhanced the significant concept for radio communication approach techniques for future generation networks. In each orthogonal resource block, traditional OMA systems such as Orthogonal Frequency Division Multiple Access (OFDMA) and Time Division Multiple Access (TDMA) serve a single user. However, various 5G multiple access technologies, such as NOMA, serve many users in each orthogonal resource block, including Lattice Partitioning Multiple Access (LPMA), Pattern Division Multiple Access (PDMA), Sparse Code Multiple Access (SCMA), and Low-Density Spreading (LDS) [1]. Despite the poor channel conditions in OMA, the user has exclusive access to the bandwidth resources, which harms the spectrum efficiency and performance of the system. When NOMA is employed in this situation, it ensures that not only the user with poor channel conditions is served, but users with adequate channel capacity may also share the same bandwidth resources as the weak user. As a result, if user fairness must be ensured, then the system performance of NOMA can be much higher than OMA. NOMA can efficiently support vast connections, which is necessary for 5G, in addition to its spectral efficiency improvement. Different multiplexing techniques have been evolved as telecommunication generations progressed to the fifth generation (5G) from the first generation (1G), as shown in Table I.

TABLE I
COMPARISON OF GENERATIONS WITH DIFFERENT FEATURES

Generations and its features	1G	2G	3G	4G	5G
Time Period	1970 to 1980	1990 to 2000	2004 to 2005	2010	2020
Data bandwidth	1.9 kbps	64kbps	2Mbps	2Mbps to 1Gbps	1Gbps & Higher
Core network	PSTN	Packet network of PSTN	Packet Network	All IP Network	Flatter IP network & 5G network interfacing
Handoff	Horizontal	Horizontal	Vertical and Horizontal	Vertical and Horizontal	Vertical and Horizontal
Multiple Access	FDMA	CDMA, TDMA	CDMA	OFDMA	NOMA (PDM,CDM)
Frequency	800 to 900 Reference MHz	850 to 1900 MHz	1.6 to 2.5 GHz	2 to 8 GHz	Up to 39 GHz
Standards	NMT, AMPS	GSM, GPRS, EDGE	WCDMA, CDMA-2000	OFDMA	CDMA & BDMA
Service	Analog voice	Digital voice	High quality data, audio and video	Global roaming, HD streaming	Dynamic information access, global roaming, HD streaming

The improvement of achievable capacity rate and system performance is the top priority in response to the rising number of connected systems. As a result, NOMA is viewed as a potential future radio access approach that addresses these issues. Although 3G offers a higher Quality of Service (QoS), it suffers from near-far issues and self-interference as the number of users rises [2]. In

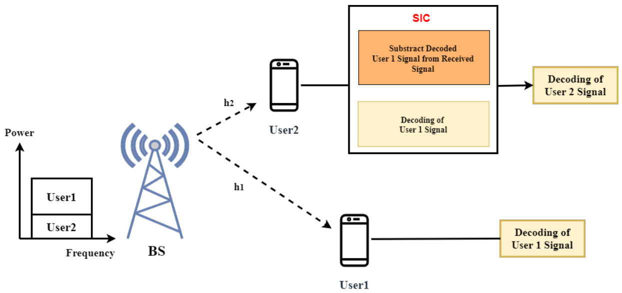

Fig. 1. Basic Concepts Non-Orthogonal Multiple Access (NOMA)

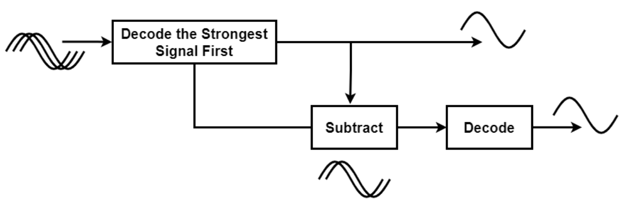

Fig. 2. Successive Interference Cancellation

4G networks, OFDM is used in addition to FDMA and TDMA.

The essential theory of NOMA is shown in Fig. 1. Both users are served with the same frequency and time with different power levels. Low power is allotted to user 2 (near user) and high power is allotted to user 1 (far user). To make sure reception of user-specific messages, NOMA utilizes super position-coding at the transmitter and Successive Interference Cancellation (SIC) at the receiver.

In Fig. 2, the information signals are multiplexed at the transmitter. SIC decodes the first signal as the strongest one while others as interference. The first decoded signal is then subtracted from the received signal and if the decoding is accurate, the rest of the signals are accurately recovered. Therefore, we successfully cancel the interference from the estimated symbol. SIC repeats the procedure until the desired signal is found [3].

The rest of the paper is discussed as follows. In section II, the advancement from OMA to NOMA concept is discussed. The primary concept of NOMA is presented in section III. In section IV, enabling technologies for NOMA and 5G are discussed. Results are discussed in section V. In section VI, research goals and future challenges of NOMA are presented. Finally, section VII concludes the paper.

II. The Advancement From OMA To NOMA Concept

OMA techniques may achieve high system performance even with basic receivers in an ideal situation due to minimal mutual interference among users, but, they are still unable to solve the rising issues posed by current demands in 5G networks. Fig. 3 shows that NOMA is capable of achieving an excessive transmission rate than OMA. The bandwidth is divided in OMA, but there is no bandwidth division in the NOMA system. So whole bandwidth is assigned to both the users in NOMA. In OMA, the user takes half of the bandwidth with no interference, but SIC is required for the NOMA system.

In OMA, each user is given a specific frequency resource irrespective of whether the channel is robust or inadequate and it gives less spectral efficiency and weak performance to the system. However, with NOMA, the same frequency resource is allotted to several mobile users at the same time, with both strong and unfavorable channel conditions [4]. As a result, the resource given to the weak user is also used by the strong user, and interference may be minimized using SIC techniques at the receivers of both users. As a result, the possibility of better spectral efficiency and high performance will be significantly increased [5].

The user with a better channel condition has a maximum priority to be serviced in OMA, but the user with a bad channel state must wait for access, which leads to fairness issues and severe latency. This method is incapable of supporting large-scale connectivity. On the other hand, NOMA systems serve several users with different channel conditions at the same time, resulting in higher user fairness, reduced latency, and more network capacity [6]. NOMA is a desirable design choice because it provides higher system efficiency, higher spectral efficiency to accommodate the massive connectivity of 5G devices, improved user performance and fairness compensation, high transmission speed, superior multi-user capacity, compatibility with other access technologies, and low transmission latency.

III. Primary Concepts of NOMA

The functioning principles and variations of both uplink and downlink NOMA transmissions are introduced in this section. Here, the achievable capacity, Signal to

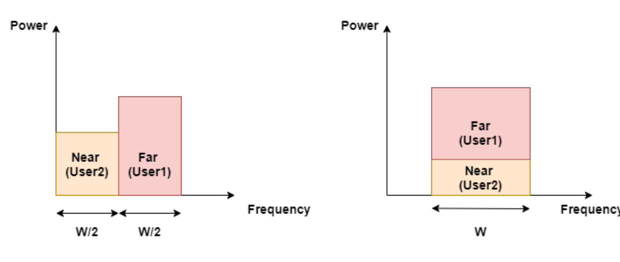

Fig. 3. Capacity comparibility of OMA and NOMA

Noise Ratio (SNR), and sum-rate analysis are calculated for the downlink NOMA system.

A. Downlink NOMA Network

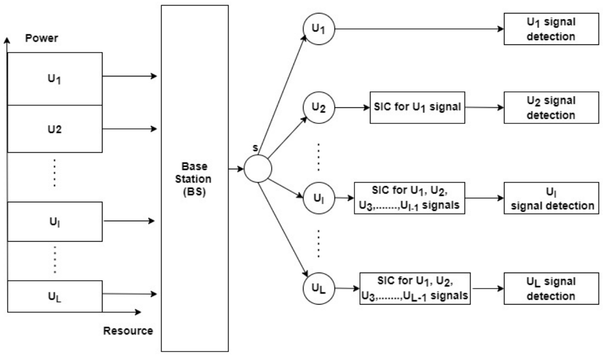

Fig. 4. Downlink NOMA Network

The Base Station (BS) transmits the merged signal, which is a superposition of multiple users' desired signals with dissimilar assigned power coefficients, to every mobile user at the transmitter side of the downlink NOMA network, as shown in Fig. 4. The SIC procedure is assumed to be carried out sequentially at each user's receiver until the signal of the user is retrieved. Users' power coefficients are distributed in an inversely proportional manner according to their channel conditions [7]. A user with a poor channel order is given more transmission power than one with a better channel order. As a result, the user with the maximum transmitting power appraises other users' signals to be noise and recuperates its signal quickly, without going through any SIC procedures. On the other hand, other users must conduct SIC procedures. Each user's receiver identifies the signals that are robust than its own desired signal first in SIC. The obtained signal is then subtracted from those signals, and the procedure is repeated until the relevant user's signal is calculated. The following is a representation of the transmitted signal at the base station [8].

$$T = \sum_{i=1}^{L} \sqrt{a_i P_t} x_i \tag{1}$$

where T is the transmitted signal, x_i is the information of user i, a_i is the power coefficient allocated for user i subjected to $\sum_{i=1}^{L} a_i = 1$ and $a_1 \geq a_2 \geq a_3 \geq \cdots \geq a_L$, and P_t is the transmission power at the base station.

The received signal at l^{th} user can be calculated as follows

$$R_l = h_l T + w_l = h_l \sum_{i=1}^{L} \sqrt{a_i P_t} x_i + w_l \tag{2}$$

where, h_l is the channel coefficient for l^{th} user, w_l is the zero mean complex additive Gaussian noise with a variance σ^2.

The achievable capacity of OMA can be calculated as

$$C_{l,OMA} = \frac{1}{N} \log_2(1 + SNR_{l,OMA}) \tag{3}$$

where N = Number of channels

$$SNR_{l,OMA} = \frac{P_T |h_l|^2}{\sigma^2}$$

The achievable capacity of NOMA can be calculated as

$$C_{l,NOMA} = \log_2(1 + SNR_{l,NOMA}) \tag{4}$$

where

$$SNR_{l,NOMA} = \frac{a_l \gamma |h_l|^2}{\gamma |h_l|^2 \sum_{i=l+1}^{L} a_i + 1}$$

and

$$\gamma = \frac{P_T}{\sigma^2}$$

The sum-rate of the downlink NOMA can be taken down as

$$R_{sum}^{NOMA} = \sum_{l=1}^{L} \log_2(1 + SNR_{l,NOMA}) \tag{5}$$

B. Uplink NOMA Network

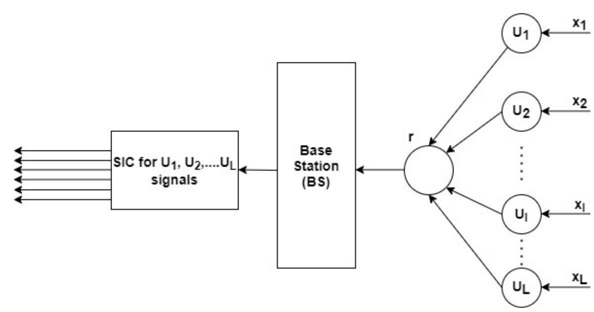

Fig. 5. Uplink NOMA Network

All mobile user transmits their signal to the BS in an uplink NOMA network, as shown in Fig. 5. The signal of user 1 is first marked and deducted from the superimposed signal obtained at the BS utilizing SIC. When compared to downlink NOMA, uplink NOMA is less complex to implement and it has high spectral efficiency. Since SIC is carried out at BS, which is a centralized organization with smaller energy limitations than an individual consumer with limited processing capacity, it consumes less energy. Numerous users communicate their signals to the same BS in the equal resource block in an uplink NOMA device, with dissimilar power levels.

In comparison to downlink NOMA, the transmit power levels of any given user in uplink NOMA do not affect the transmit power of any other user for a stated user pair and also both users can utilize their transmit powers independently [9] - [10]. The output is more dependent on the received SNR at the BS. When compared to power-regulated OMA, NOMA performs better in terms of fairness [11].

IV. Enabling Technologies For NOMA And 5G

NOMA's integration with 5G enabled methodologies helps leverage the power domain to support many users with increases in Spectral Efficiency (SE), great connectivity, device fairness, increased coverage area, low latency, higher bandwidth gains, better data speeds, and improved performance.

A. Heterogeneous Network (HetNet) and NOMA

Network traffic is increasing as a result of the proliferation of smart devices. The pressure on network bandwidth necessitates spectrally efficient technologies, HetNets is a technology that adds a vast number of small, low-power cells to an available high-power macro-cell substructure [12]. This method of cell condensation offers advantages such as better expanded coverage increases network capacity, enhances quality of service, increases connectivity, and effective spectrum usage by frequency reuse in much larger areas [13]. The amalgamation of HetNets and NOMA is a promising strategy for 5G and upcoming generation networks since both mechanisms are spectrally coherent and increase bandwidth. In NOMA, the idea of user matching can lead to the expansion of connected devices and thus boost system efficiency.

B. Massive Machine-Type Communications (mMTC) and NOMA

Massive Machine-Type Communication (mMTC) is a crucial feature of 5G communication services, as well as a scalable connectivity stipulation for increasing the number of wireless devices while transmitting small amounts of data efficiently over long distances. It's also important in body-area networks, the Internet of Things, drone deliveries, and smart homes. The availability of the connectivity required to enable large numbers of machine-to-machine interactions limits the development of mMTC. Small data packets are used in this sort of communication, which is not well supported by cellular networks. To handle a variety of communications across several frequency bands, such networking would have to be safe, dependable, and reliably scalable with high capacity and low latency, and to work efficiently in congested urban or indoor contexts, mMTC must have a low cost and energy consumption, as well as the penetration required. NOMA has appeared as a viable solution that permits numerous users to share a radio resource, allowing for independent and grant-free communication in which devices can send data whenever they demand it. In the current environment, NOMA with mMTC is an enabling technology for future wireless communication generations (5G) technology.

C. Simultaneous Wireless Information and Power Transfer (SWIPT)-NOMA

Most gadgets are battery-powered and use numerous powers during transmission, reception, and information relaying. Energy efficiency is a distinct issue being considered in 5G communications. These systems should be able to work for longer periods [14]. Replace batteries regularly may be one way to solve energy deficiency, but this would entail a crucial number of assets in terms of operating values, unapproachable, and time, which would outweigh the sake of utilizing cellular connectivity. As a result, in the matter of reducing energy utilization and prolong the life of wireless devices, various network methods are used, including designing energy awake algorithms that allocate unlike duty cycle relationships to gadgets, circumstance-based communication, broadcasting tablet data, and energy harvesting using solar or wind energy [15]. SWIPT, an evolving technique that picks energy from RF signals, is a more appropriate and versatile solution for powering energy-compelled devices [16]. It has the advantages of extending network durability, systematic transmission because power and data are communicated simultaneously, and the ability to use interfering signals as possible Energy Harvesting (EH) sources.

D. Enhanced Mobile Broadband(eMBB)-NOMA

Enhanced Mobile Broadband (eMBB) is a step forward from LTE, which can currently deliver gigabit-class mobile internet speeds in some markets. Even still, as more devices connect to networks around the world, the need for higher bandwidth, more connectivity, and reduced latency in crucial applications has already outstripped LTE's capacity. It includes 3D video streaming on virtual reality and online gaming, 4K screens, necessitates ultra-high data rates, and broad network coverage. When compared to 4G, peak data speeds for eMBB are predicted to be 1000 times quicker. The idea of using enhanced mobile broadband to help NOMA has been well received, and its implementation is presently being considered.

E. Ultra-Reliable Low-Latency Communication (URLLC)-NOMA

Ultra-Reliable Low-Latency Communication(URLLC) is a fast, brief mechanism that may be a workaround to connect health care, high-speed train comparability, remote surgery, mission-critical applications, vehicular communications, and smart industry implementation will dispose of low latency, reliability, and mobility. NOMA is being utilized to help URLLC handle time-critical applications by reducing latency and increasing reliability.

F. Unmanned Aerial Vehicles (UAV)-NOMA

Unmanned Aerial Vehicles (UAVs) are low-charge, dependable, and simple-to-deploy high-quality technology which supports high data rates and universal affinity to a wide range of gadgets. This fascinating automation has the potential to improve service areas, productivity, power, and energy efficiency. Military, emergency prevention, traffic control, security, telecommunications, and photography have all used this application [17]. The use of UAVs to assist NOMA has lately sparked delight and is currently being sought.

G. Mobile Edge Computing (MEC) assisted NOMA

With the quick advancement of mobile wireless networking, there is a volatile rise in the utilization of data networks to operate the applications based on supercomputers and enlightened mobile established implementations like virtual reality, online video games, and different computer-based applications. Generally, radio devices are limited to execute such assignments due to insufficiency of battery and high latency [18]. The concept of Mobile Edge Computing (MEC) was initiated to minimize latency and extend the life of mobile devices. MEC-assisted NOMA decreases energy utilization and network latency, resulting in better QoS for users.

H. Intelligent Reflective Surfaces assisted NOMA

The obtained signals are often degraded by variations in a wireless channel. Intelligent Reflective Surfaces (IRS), a relatively new spectral and energy-efficient technology, may be able to reduce radio signal loss caused by nearby clutter. IRS is made up of a group of intelligent reflecting array components that can absorb energy and change the phase of incident rays.

V. Results and Discussion

In this section, all simulation results are presented to validate our analysis through Rayleigh and Rician fading channels about different transmit power. In Fig. 6, we plot and compare the achievable capacity of OMA and NOMA systems by using (3) and (4) respectively. Fig. 7 and 8 illustrate the BER performance and sum rate analysis of far user and near user NOMA systems respectively. Here we have assumed different power allocation factor for different users (a_1=0.75 (far), a_2=0.25 (near)). Based on the results, it can be shown in Fig. 6 that the NOMA system outperforms the OMA system in terms of achievable capacity with different fading channels. From Fig. 7 and 8, the Rician fading channel gives better performance than Rayleigh fading channels in terms of BER and sum-rate measurement for different users.

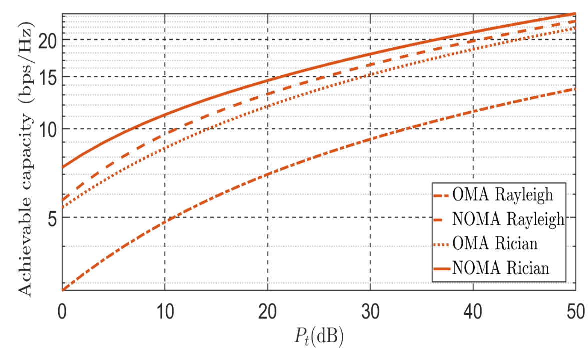

Fig. 6. Transmit Power Vs Achievable Capacity

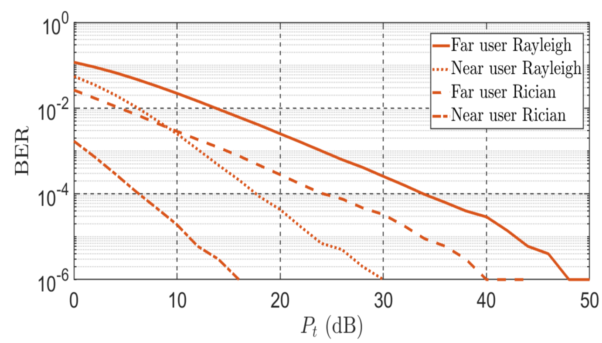

Fig. 7. Transmit Power Vs BER

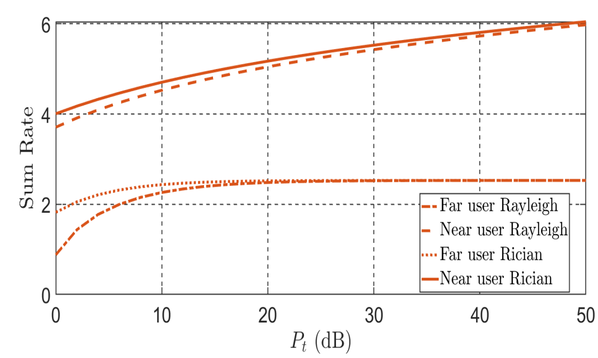

Fig. 8. Transmit Power Vs Sum Rate

VI. Research Goals And Future Challenges

Even though NOMA is one of the future 5G multiple access strategies, there are still some limitations and difficulties that need to be addressed. Even after, the majority of practical implementations use a two-user pairing concept, with only a few studies considering three-user pairing schemes in NOMA. For multi-user detection or resource allocation, perfect Channel State Information (CSI) is assumed in most NOMA systems. However, CSI is not feasible, hence channel estimate errors exist in NOMA. However, as the number of users in future 5G networks grows, there will be severe inter-user interference, which might lead to severe channel estimate errors. As a result, the more advanced channel estimating algorithms are necessary for NOMA systems to provide accurate channel estimates. Apart from these, user mobility in a NOMA system is an important topic that entails being inscribed in forthcoming research, especially for vehicular networks. The majority of NOMA research has concentrated on single-cell NOMA systems, with multi-cell NOMA techniques receiving relatively little attention. 5G and succeeding generation radio networks are supposed to use a mix of multiple access techniques rather than fully replacing existing OMA techniques with NOMA.

VII. Conclusion

The main principle and benefits of the NOMA approach, which are one of the most exciting innovations for succeeding 5G networks, have been explored in this paper. NOMA is anticipated to take part in a crucial role in 5G and upcoming wireless networks for high connectivity and low latency. It also features several challenges and opening exploration patterns relevant to NOMA. In this paper, we simulated the achievable capacity of OMA with NOMA, BER, and sum-rate concerning transmit power in near user and far user scenarios based on various fading channels. The simulation results reveal that the Rician fading channel provides better outcomes as compared to the Rayleigh fading channel in the NOMA system due to a smaller number of deep fades and a stronger line-of-sight path. Also, the study can be done in the future for these along with a large cluster of NOMA systems.

References

[1] L. Dai, B. Wang, Z. Ding, Z. Wang, S. Chen, and L. Hanzo, "A Survey of Non-Orthogonal Multiple Access for 5G," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 3, pp. 2294-2323, 2018.

[2] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan, and V. K. Bhargava, "A Survey on Non-Orthogonal Multiple Access for 5G Networks: Research Challenges and Future Trends," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2181-2195, 2017.

[3] M. R. Islam, N. Avazov, O. A. Dobre and K. Kwak, "Power Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 721-742, 2017.

[4] Y. Liu, Z. Ding, M. Elkashlan, and H. V. Poor, "Cooperative Non-Orthogonal Multiple Access with Simultaneous Wireless Information and Power Transfer," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 4, pp. 938-953, April 2016.

[5] M. Baghani, S. Parsaeefard, M. Derakhshani and W. Saad, "Dynamic Non-Orthogonal Multiple Access and Orthogonal Multiple Access in 5G Wireless Networks," *IEEE Transactions on Communications*, vol. 67, no. 9, pp. 6360-6373, Sept. 2019.

[6] K. M. Rabie, B. Adebisi, E. H. G. Yousif, H. Gacanin and A. M. Tonello, "A Comparison Between Orthogonal and Non-Orthogonal Multiple Access in Cooperative Relaying Power Line Communication Systems," *IEEE Access*, vol. 5, pp. 10118-10129, 2017.

[7] B. Makki, K. Chitti, A. Behravan, and M. S. Alouini, "A Survey of NOMA: Current Status and Open Research Challenges," *IEEE Open Journal of the Communications Society*, vol. 1, pp. 179-189, 2020.

[8] M. Aldababsa, M. Toka, S. Gokceli, G. K. Kurt, and O. Kucur, "A Tutorial on Nonorthogonal Multiple Access for 5G and Beyond," *Wireless Communications and Mobile Computing*, 2018.

[9] X. Chen, D. W. K. Ng, and H. Chen, "Secrecy wireless information and power transfer: challenges and opportunities," *IEEE Wireless Communications*, vol. 23, no. 2, pp. 54-61, April 2016.

[10] P. D. Diamantoulakis, K. N. Pappi, Z. Ding, and G. K. Karagiannidis, "Wireless-Powered Communications with Non-Orthogonal Multiple Access," *IEEE Transactions on Wireless Communications*, vol. 15, no. 12, pp. 8422-8436, Dec. 2016.

[11] W. Wu, X. Yin, P. Deng, T. Guo, and B. Wang, "Transceiver Design for Downlink SWIPT NOMA Systems With Cooperative Full-Duplex Relaying," *IEEE Access*, vol. 7, pp. 33464-33472, 2019.

[12] 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, July 2017.

[13] J. Tang *et al.*, "Energy Efficiency Optimization for NOMA with SWIPT," *IEEE Journal of Selected Topics in Signal Processing*, vol. 13, no. 3, pp. 452-466, June 2019.

[14] M. Hedayati and I. Kim, "On the Performance of NOMA in the Two-User SWIPT System," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 11, pp. 11258-11263, Nov. 2018.

[15] H. Zhang, N. Yang, K. Long, M. Pan, G. K. Karagiannidis, and V. C. M. Leung, "Secure Communications in NOMA System: Subcarrier Assignment and Power Allocation," *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 7, pp. 1441-1452, July 2018.

[16] J. Tang *et al.*, "Joint Power Allocation and Splitting Control for SWIPT-Enabled NOMA Systems," *IEEE Transactions on Wireless Communications*, vol. 19, no. 1, pp. 120-133, Jan. 2020.

[17] A. A. Nasir, H. D. Tuan, T. Q. Duong, and H. V. Poor, "UAV-Enabled Communication Using NOMA," *IEEE Transactions on Communications*, vol. 67, no. 7, pp. 5126-5138, 2019.

[18] X. Duan, B. Li, and W. Zhao, "Energy Consumption Minimization for Near-Far Server Cooperation in NOMA-Assisted Mobile Edge Computing System," *IEEE Access*, vol. 8, pp. 133269-133282, 2020.