Power-Domain Non-Orthogonal Multiple Access for Realistic Transmission

Abdulah Jeza Aljohani[1†] and Ibrahim Almujtaba[1],

Department of Electrical and Computer Engineering, King Abdulaziz University
Jeddah 21589, Saudi Arabia

Abstract
Non-orthogonal multiple access (NOMA) has emerged as a new multiple access paradigm for 5G wireless networks. Although many results have been produced for NOMA, most of them are limited to theoretical exploration and performance analysis. A limited progress is made in employing NOMA schemes into a realistic scenario. In this paper, we introduce a downlink power-domain NOMA (PD-NOMA) into a realistic transmission. We first design a cell area where we randomly deployusers around a base station (BS). The BS has the ability to identify the best NOMA pairs, Namely, near and far users, among all users. The BS will then allocate the power to both near and far users. Our zero forcing (ZF)-aided successive interference cancellation (SIC) detector is capable of successfully removing the interference of the near user signals as documented in the bit error ratio (BER) results.

Key words:
Non-orthogonal multiple access (NOMA), 5G, power-domain NOMA.

1. Introduction

Non-orthogonal multiple access (NOMA) constitutes a spectrum-efficient solution that can accommodate the huge data traffic of the 5G networks. In contrast with the classical orthogonal multiple access (OMA) techniques, such as frequency division multiple access (FDMA), and code division multiple access (CDMA), NOMA is able to support multiple users using the same (time/frequency/code) resource block. This can be achieved by superimposing users' signals at the transmitter and the use of successive interference cancellation (SIC) at the receivers. Motivated by the improved spectral efficiency provided by NOMA, several combined NOMA-aided multiple-input multiple-output (MIMO) schemes have been proposed recently [1,2,3]. However, designing efficient combined schemes will include several challenging including: power allocations, users' coordination, and user's clustering/selection [2]. For example, in [1] a joint user selection with optimized beamforming scheme was proposed for millimeter wave (mmWave) communication.
NOMA techniques can be categorized into two methods: code-domain and power-domain [4]. The code-domain NOMA (CD-NOMA) utilizes the random Gaussian codes at the transmitters while the compressive sensing is employed at the receiver aiming to maximize the user's detection, while to minimize symbol error rates. The sparsity of the transmitted signal allows the use the low-density spreading coding-aided CMDA (LDS-CDMA), and LDS-aided OFDM (LDS-OFDM). In the power-domain NOMA (PD-NOMA), multiple user signals are jointly superimposed using the same (frequency/time/code) resource by allocating different power-level for each user. At receiver, to decode the users' message signals a SIC or dirty paper coding (DPC) can be employed [5, 6].
In this paper, we will first propose a zero forcing (ZF)-based SIC for PD-NOMA scheme. Then we evaluate the performance of the PD-NOMA transmission. Next, we introduce our system into a realistic scenario of a downlink transmission, where the base station (BS) can choose the best NOMA users.
A literature review will be presented in Sec. 2. While in Sec. 3, the proposed system model and its result will be discussed. The realistic transmission scheme and the results are analyzed in Sec. 4, and Sec. 5, respectively. Finally, our conclusion will be offered in Sec. 6.

2. Related Works

Enormous number of researches have been demonstrated that NOMA systems can fulfill the requirements of fifth generation (5G) [1, 2, 3]. For example, PD-NOMA was analyzed when transmitting over a fading channel in [7], where it was shown that NOMA techniques can increase the spectral efficiency significantly when compared with OMA counterparts. In [6], the researchers adopt novel SIC receiver in downlink-NOMA transmission, considering the future expected improvement of device processing. Based on the system-level evaluations of [6], NOMA scheme improved both the throughput of cell-edge user and the

Manuscript received October 5, 2020
Manuscript revised October 20, 2020
https://doi.org/10.22937/IJCSNS.2020.20.10.4

overall capacity. A survey of the NOMA schemes' progress provided in [8], where it includes the capacity analysis, user fairness, power allocation strategies, and user-pairing schemes.

A study of the power-efficient resource allocation for multi-carrier (MC) NOMA systems introduced in [10]. The study proposed users' scheduling and sub-optimal power allocation with low computational complexity [10]. An overview of promising modulation schemes-aided NOMA provided in [11], where the spectral efficiency, out-of-band leakage, and BER performances were discussed. While in [12] a power allocation-aided beamforming proposed for downlink NOMA scenario, where a significant power reduction was exhibited.
In [13], beamforming-aided NOMA scheme were employed to decrease the transmitted power for the downlink 2-user MISO transmission. A half zero forcing (ZF) detection used to reduce the interference from the cell-interior user's signal [13]. Compared with the conventional ZF method, half-ZF can acquire lower power consumption. A combination of power allocation and beamforming in a downlink MIMO multi-user system which employs NOMA presented in [14].
A multicast beamforming-aided superposition modulation (SPM) proposed for multi-resolution broadcast in [15]. More explicitly, users' messages of low and high priorities are to be transmitted for the near user, while only message of low priority is to be transmitted to far user. Moreover, a multi-user NOMA beamforming problem formulated as a semi-definite programming problem and generalized to include the conventional multi-user beamforming in [16]. The authors studied a low-complexity approach to decide successive interference cancellation sets for the generalized NOMA. They showed that their proposed method can have a better performance than the conventional BF.

In [17], a NOMA-based multiuser beamforming system were proposed aiming to enhance the overall capacity. While in [18], a NOMA with SIC in downlink multi-user MIMO cellular systems investigated, where the number of receive antennas is more than the total number of antennas in the transmitter side. The proposed linear beamforming technique showed that the capacity gain performance is significantly improved when compared with MIMO-OMA counterpart. Finally, a comprehensive NOMA survey offered in [19].

3. System Model

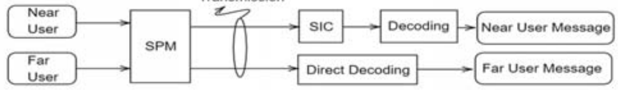

Figure 1. Power-Domain NOMA schematic diagram.

The schematic of the overall PD-NOMA scheme is shown in Fig. 1. The two users' signals, namely near user and far user will be superimposed into a one signal before the transmission. Superposition modulation (SPM) is a widely known technique for non-orthogonal transmission scheme [20], where two-or-more messages are transmitted simultaneously by encoding them into a signal. The SPM constellation of combining two QPSK signals into a 16QAM constellation is illustrated in Fig. 2.

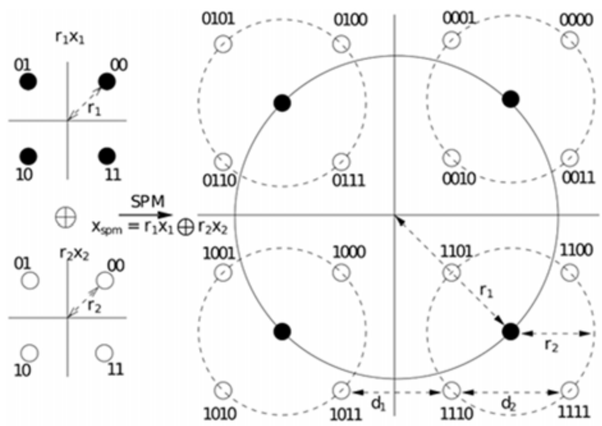

Figure 2: Constellation diagram explaining superposition coding for PD-NOMA system.

For example, the QPSK modulated signals $\boldsymbol{s_1}$ and $\boldsymbol{s_2}$ will be linearly combined to generate a 16QAM $\boldsymbol{X_{SPM}}$ as:

$$\boldsymbol{X_{SPM} = r_1 s_1 + r_2 s_2} \qquad (1)$$

where $\boldsymbol{r_1}$ and $\boldsymbol{r_2}$ are scaling factors. The power allocated for both equals to one, i.e. $\boldsymbol{r_1 + r_2 = 1}$. Note that, the signal with bigger allocated scaling power factor is more protected, as illustrated in Fig. 2.

SUCCESSIVE INTERFERENCE CANCELLATION (SIC)

A typical MIMO system can be described as:

$$\boldsymbol{y = Hx + n} \qquad (2)$$

where $\boldsymbol{H}$ is the channel matrix, where we consider a Rayleigh fading channel, $\boldsymbol{x}$ is the transmitted signal, and $\boldsymbol{n}$ denotes the AWGN with mean zero and variance σ_N^2.
At the receiver, typically, two common reduced-complexity detectors are considered, namely zero-forcing (ZF), and minimum mean square error (MMSE) [21]. The ZF detector only eliminates the channel effect only, where the channel equalization matrix $\boldsymbol{w_{ZF}}$ can be given as:

$$\boldsymbol{w_{ZF} = H^H (HH^H)^{-1}} \qquad (3)$$

where superscript "$\boldsymbol{H}$" denotes the Hermitian transpose operation. While the MMSE detector considers removing the impacts of both fading and the additive noise, as its equalization matrix $\boldsymbol{w_{MMSE}}$ can be given by:

$$\boldsymbol{w_{MMSE} = H^H \left(HH^H + diag(\sigma_N^2)\right)^{-1}} \qquad (4)$$

It is worth mentioning that the complexity of the linear detectors, MMSE and ZF, is often lower than that of nonlinear ones [22]. In our proposed system we opted to employ the ZF scheme. More explicitly, in our transmission the far user's signal will be allocated with higher transmitted power, when compared to the near user. Hence, the SIC will be invoked at the near user's receiver aiming to cancel the far user's signal first. Consequently, the far user will be able to detect its signal directly without employing SIC. A code-word level-aided SIC algorithm is implemented, as illustrated in Fig. 3.

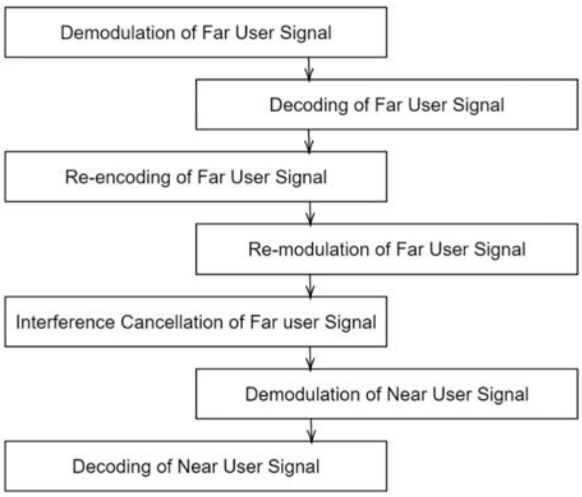

Figure 3: Flow Chart for Codeword-Level SIC.

More explicitly, the superimpose transmitted signal of both users can be written as:

$$X_{SPM} = r_1 s_{far} + r_2 s_{near} \qquad (5)$$

where, we assume perfect synchronous transmission between both users. While the received signals at both near and far receivers can be expressed, respectively, as:

$$\begin{aligned} z_{far} &= g\, X_{SPM} + n_{far} \\ &= g\,(r_1\, s_{far} + r_2\, s_{near}) + n_{far} \qquad (7) \end{aligned}$$

$$\begin{aligned} z_{near} &= h\, x + n_{near} \\ &= h\,(r_1\, s_{far} + r_2\, s_{near}) + n_{near} \qquad (8) \end{aligned}$$

where h and g represent the block Rayleigh fading channels. Note that, we chose to select that $r_1 > r_2$, , the SIC will be performed at the near user's only, where the far user's signal, s_{far}, will be treated as an interference and will be removed in a code-word manner, as explained in Fig. 3. However, the far user will be able to detect his signal directly as the s_{far} will be allocated will less power, hence, diminishing during the transmission. Fig. 4 illustrates the detection process of both users.

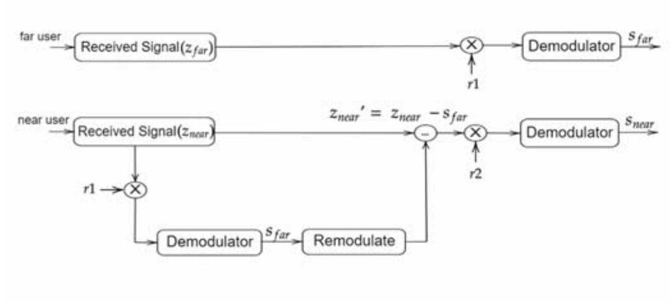

Figure 4: The downlink power domain NOMA Receiver.

The bit error ratio (BER) performance of the PD-NOMA transmission is portrayed in Fig. 5. Both the far and near users are allocated power factors of $r_1 = 0.8$, and $r_2 = 0.2$, respectively. Each user employs a QPSK, where both signals are combined into a 16QAM-SPM, as shown in Fig. 2. The superimposed signal will be transmitted through AWGN and Rayleigh fading channels. Our ZF-aided SIC at the near-user receiver could remove most of the interference caused by the far user's signal, as Fig. 5 suggested. The far user performers better, as its signal has been allocated with the more power factor, when compared to the near user.

Finally, as expected, the proposed system performs significantly better when encountering the AWGN channel.

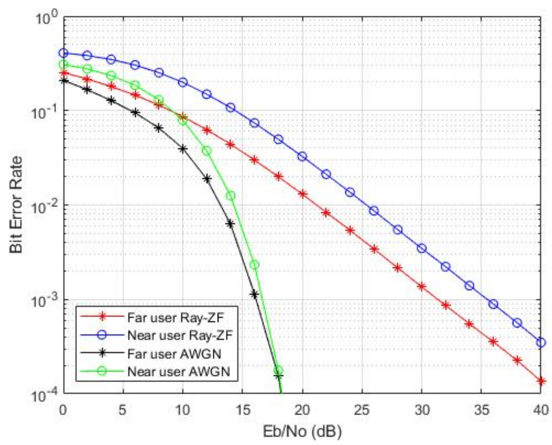

Figure 5: BER performance of PD-NOMA, where the simulation parameters is listed in Table 1.

Modulation Scheme	QPSK
Mapper Type	16QAM-SPM
Bandwidth	20 MHz
Base Cell Size	1000 (m)
Number of Bits	100,000
Number of Users in Cell	50 Users
Channel	AWGN & Rayleigh Fading
Channel State Information (CSI)	Known
MUD Type	Zero Forcing

Table 1: Simulation parameters of BER curves of Fig. 5.

4. NOMA Realistic Transmission

Consider the single cell downlink network of Fig. 6 that is with one base station (BS). The BS serves a set of randomly deployed 50 users, from which it will nominate potential NOMA users. To elaborate further, the BS compares each nearby couple of users' angles, the two users with angle difference less than "$\pi/12$" considered as a potential NOMA user. Note that, the angle of each user is estimated with respect to the BS, and we opted to the to select the "$\pi/12$", as it shows better results heuristically. Next, the BS will choose the real NOMA users among the potential NOMA users cardinalates, by assessing the quality of the downlink wireless channel, as illustrated in Fig. 6. That is to say, the BS will evaluate the ability of the near user to cancel the interference caused by the far user.

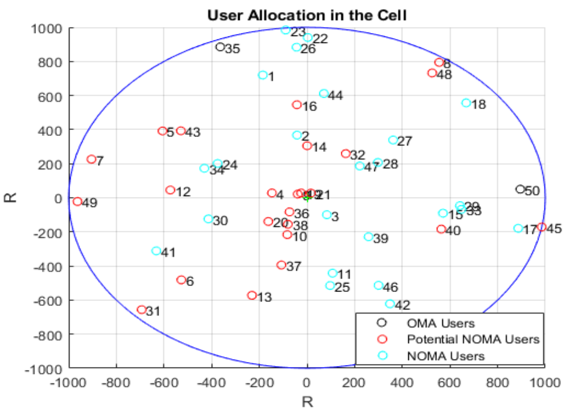

Figure 6: A 1-km diameter cell of 50-users randomly deployment, showing both potential and real NOMA users.

In our scenario, we deploy 50 users randomly where we found that 48 users can potentially be NOMA-based users where from which 24 users are considered as a real NOMA user. Fig. 7 illustrates the procedure of selections NOMA users. We assume that the BS has a full channel state information (CSI) that will used to estimate the needed power allocations for the NOMA users' pair.

When NOMA mode is activated, the BS superimposes both near and far users' signals using Eq. (1), where again $\boldsymbol{r_1} + \boldsymbol{r_2} = \mathbf{1}$.

In the receiver, ZF-SIC is invoked, where we decode the far user signal first then re-modulate it, to remove its interference using SIC method to decode he near user denoted by $\boldsymbol{s_{near}}$ successively, as Fig. 4 shows. The far user decodes its signal denoted by $\boldsymbol{s_{far}}$ directly without using SIC. The received signals at two users, namely $\boldsymbol{z_{far}}$ and $\boldsymbol{z_{near}}$ can be estimated using Eq. (7) and Eq. (8), respectively.

The Signal-to-Interference-plus-Noise-Ratio (SINR) of the far user message at the near user receiver is denoted as ζ_{far} and can be expressed as:

$$\zeta_{far} = \frac{|h^H r_1|^2}{|h^H r_2|^2 + \sigma_{near}^2} \qquad (9)$$

While the SINR needed to decode the near user is denoted as ζ_{near} and is given by:

$$\zeta_{near} = \frac{|h^H r_2|^2}{\sigma_{near}^2} \qquad (10)$$

The achievable rate of decoding messages of far and near users can be expressed respectively as:

$$R_{far} = \frac{B}{U} \log_2 \left(1 + \frac{P_{far} G_{far}}{G_{far} + \sigma^2}\right) \qquad (11)$$

$$R_{near} = \frac{B}{U} \log_2 \left(1 + \frac{P_{near} G_{near}}{\sigma^2}\right) \qquad (12)$$

Where $\boldsymbol{B}$ denotes the Bandwidth, $\boldsymbol{U}$ is the number of users, and $\boldsymbol{G}$ denotes the channel gain.

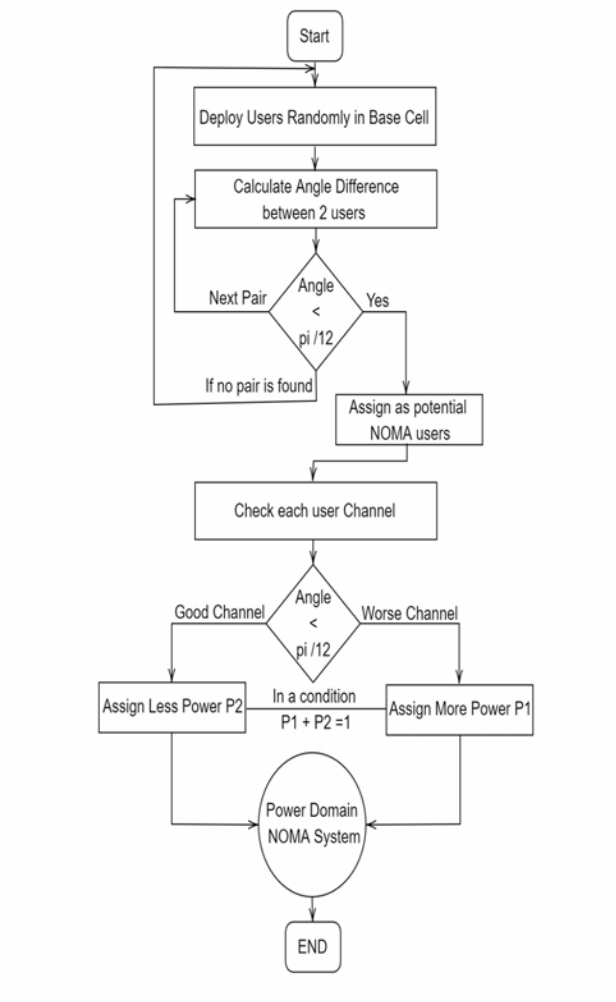

Figure 7: The flow chart of selecting the NOMA users among all potential users.

5. Simulation Results

The BER performance of 3 pairs of PD-NOMA users is shown in Fig. 8. Note thar, in each pair the two users allocated power must be equal "1" which satisfies $\boldsymbol{r_1 + r_2 = 1}$.
We consider a downlink transmission where each user's signal is modulated using a QPSK, and then send over a Rayleigh fading channel. The far users are allocated with more transmitted power; hence, it outperforms its near users' counterparts. Remarkably, the near users in our system are still capable of removing the inference caused by the far users, as Fig. 8 shows.

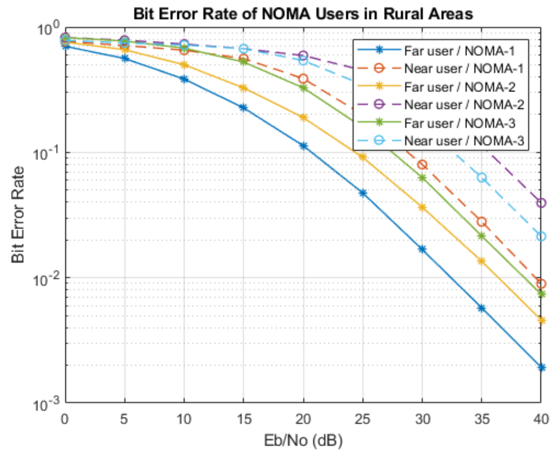

Figure 8: BER performance of 3-pairs of PD-NOMA users.

Additionally, both the individual and average sum rate of our PD-NOMA system is evaluated and depicted in the data rate for all NOMA users at each iteration as shown in Fig. 9. It can be clearly seen that implementing our NOMA scheme improves the overall system rates.

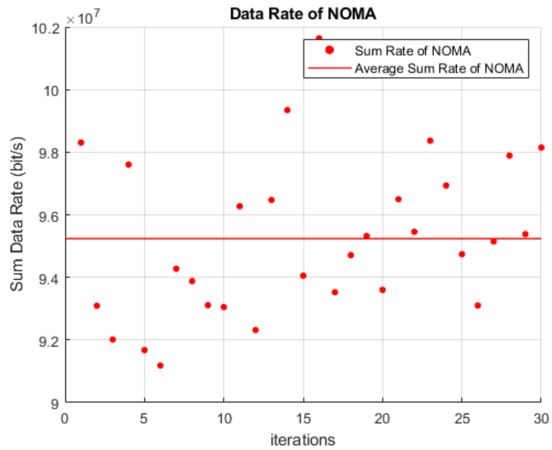

Figure 9: Data Rate of NOMA Users of the scenario of Fig. 6>

6. Conclusion

Practical NOMA transmission is proposed with various techniques, first we implemented the PD-NOMA under AWGN and Rayleigh channels and applied ZF as a SIC. Next, we tested our PD-NOMA in a realistic transmission scenario where we deployed users randomly in a cell. The BS has the capability of smartly selecting the NOMA users from the set of potential candidates. We have simulated both the BER and the overall system rate if our proposed system, where it showed a satisfactory performance.

References

[1] E. Mahmoud Mohamed, "Joint users selection and beamforming in downlink millimetre-wave NOMA based on users positioning," in *IET Communications*, vol. 14, no. 8, pp. 1234-1240, 12 5 2020.

[2] J. Ding, J. Cai and C. Yi, "An Improved Coalition Game Approach for MIMO-NOMA Clustering Integrating Beamforming and Power Allocation," in *IEEE Transactions on Vehicular Technology*, vol. 68, no. 2, pp. 1672-1687, Feb. 2019.

[3] L. Zhu, J. Zhang, Z. Xiao, X. Cao, D. O. Wu and X. Xia, "Joint Power Control and Beamforming for Uplink Non-Orthogonal Multiple Access in 5G Millimeter-Wave Communications," in *IEEE Transactions on Wireless Communications*, vol. 17, no. 9, pp. 6177-6189, Sept. 2018.

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

[5] A. Benjebbovu, A. Li, Y. Saito, Y. Kishiyama, A. Harada and T. Nakamura, "System-level performance of downlink NOMA for future LTE enhancements," *2013 IEEE Globecom Workshops (GC Wkshps)*, Atlanta, GA, 2013, pp. 66-70.

[6] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li and K. Higuchi, "Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access," *2013 IEEE 77th Vehicular Technology Conference (VTC Spring)*, Dresden, 2013, pp. 1-5.

[7] H. Sadia, M. Zeeshan and S. A. Sheikh, "Performance analysis of downlink power domain NOMA under fading channels," *2018 ELEKTRO*, Mikulov, 2018, pp. 1-6.

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

[9] P. Wang, J. Xiao and L. Ping, "Comparison of orthogonal and non-orthogonal approaches to future wireless cellular systems," in *IEEE Vehicular Technology Magazine*, vol. 1, no. 3, pp. 4-11, Sept. 2006.

[10] Z. Wei, D. W. K. Ng and J. Yuan, "Power-Efficient Resource Allocation for MC-NOMA with Statistical Channel State Information," *2016 IEEE Global Communications Conference (GLOBECOM)*, Washington, DC, 2016, pp. 1-7.

[11] Y. Cai, Z. Qin, F. Cui, G. Y. Li and J. A. McCann, "Modulation and Multiple Access for 5G Networks," in *IEEE Communications Surveys & Tutorials*, vol. 20, no. 1, pp. 629-646, First quarter 2018.

[12] J. Choi, "NOMA: Principles and recent results," *2017 International Symposium on Wireless Communication Systems (ISWCS)*, Bologna, 2017, pp. 349-354.

[13] W. Cai, G. Lv and Y. Jin, "Half-ZF beamforming scheme for downlink two-user multiple input single output-based non-orthogonal multiple access systems," in *IET Communications*, vol. 11, no. 10, pp. 1633-1640, 13 7 2017.

[14] J. Yang and W. Huang, "Joint Beamforming and Power Allocation Design in Non-Orthogonal Multiple Access Systems," *2016 International Computer Symposium (ICS)*, Chiayi, 2016, pp. 706-709.

[15] J. Choi, "Minimum Power Multicast Beamforming With Superposition Coding for Multiresolution Broadcast and Application to NOMA Systems," in *IEEE Transactions on Communications*, vol. 63, no. 3, pp. 791-800, March 2015.

[16] J. Choi, "On generalized downlink beamforming with NOMA," in *Journal of Communications and Networks*, vol. 19, no. 4, pp. 319-328, August 2017.

[17] B. Kimy *et al*., "Non-orthogonal Multiple Access in a Downlink Multiuser Beamforming System," *MILCOM 2013 - 2013 IEEE Military Communications Conference*, San Diego, CA, 2013, pp. 1278-1283.

[18] S. Ali, E. Hossain and D. I. Kim, "Non-Orthogonal Multiple Access (NOMA) for Downlink Multiuser MIMO Systems: User Clustering, Beamforming, and Power Allocation," in *IEEE Access*, vol. 5, pp. 565-577, 2017.

[19] Anwar, Asim & Seet, Boon-Chong & Hasan, Muhammad & Li, Xue Jun. (2019). A Survey on Application of Non-Orthogonal Multiple Access to Different Wireless Networks. Electronics. 8. 1355. 10.3390/electronics8111355.

[20] T. Cover, "Broadcast channels," in *IEEE Transactions on Information Theory*, vol. 18, no. 1, pp. 2-14, January 1972.

[21] Y. S. Cho, J. Kim, W. Y. Yang, C. G. Kang," MIMO-OFDM wireless communications with MATLAB," in *IEEE Press*, Wiley, 2011.

[22] Y. Ohwatari, N. Miki, T. Asai, T. Abe and H. Taoka, "Performance of Advanced Receiver Employing Interference Rejection Combining to Suppress Inter-Cell Interference in LTE-Advanced Downlink," *2011 IEEE Vehicular Technology Conference (VTC Fall)*, San Francisco, CA, 2011, pp. 1-7.

DR. ABDULAH JEZA ALJOHANI received theB.Sc (Eng.) degree in electronics and communication engineering from King Abdulaziz University, Jeddah, Saudi Arabia, in 2006, and the M.Sc. degree with distinction and Ph.D. degree, awarded with no corrections, in wireless communication from the University of Southampton, Southampton, U.K., in 2010 and 2016, respectively. He is currently an Assistance Professor with the Department of Electrical and Computer Engineering, King Abdulaziz University, Jeddah, Saudi Arabia. He is an active member of Center of Research Excellence in Intelligent Engineering Systems (CEIES). His research interests include machine learning, and optimization, distributed source coding, free-space Optical Communication, channel coding, cooperative communications, and MIMO systems.

Eng. Ibrahim Abdulrahman Almujtaba received the B.Sc (Eng.) degree in electronics and communication engineering from Umm Alqura University, Makkah, Saudi Arabia, in 2014, and the M.Sc. degree in wireless Communication from King Abdulaziz University, Jeddah, Saudi Arabia, in 2020. He is currently a Project Engineer with project management office, National Guard Health Affairs, Riyadh, Saudi Arabia. His research interests include 5th generation, and Non-Orthogonal Multiple Access (NOMA) techniques, channel coding, and MIMO systems.