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Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems

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Abstract—*Non-orthogonal multiple access (NOMA) is one of the promising radio access techniques for performance enhancement in next-generation cellular communications. Compared to orthogonal frequency division multiple access (OFDMA), which is a well-known high-capacity orthogonal multiple access (OMA) technique, NOMA offers a set of desirable benefits, including greater spectrum efficiency. There are different types of NOMA techniques, including power-domain and code-domain. This paper primarily focuses on power-domain NOMA that utilizes superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at the receiver. Various researchers have demonstrated that NOMA can be used effectively to meet both network-level and user-experienced data rate requirements of fifth-generation (5G) technologies. From that perspective, this paper comprehensively surveys the recent progress of NOMA in 5G systems, reviewing the state-of-the-art capacity analysis, power allocation strategies, user fairness, and user-pairing schemes in NOMA. In addition, this paper discusses how NOMA performs when it is integrated with various proven wireless communications techniques, such as cooperative communications, multiple-input multiple-output (MIMO), beamforming, space–time coding, and network coding, among others. Furthermore, this paper discusses several important issues on NOMA implementation and provides some avenues for future research.*

Index Terms—Non-Orthogonal Multiple Access (NOMA), Orthogonal Multiple Access (OMA), 5G, NOMA Solutions, NOMA Performance, Research Challenges, Implementation Issues.

INTRODUCTION

From analog phone calls through to all Internet Protocol services, including voice and messaging, each transition has been encouraged by the need to meet the requirements of the new generation of mobile technology. Subsequently, mobile communications technology is presently facing a new challenge, giving birth to a hyper-connected society through the emergence of fifth-generation (5G) services. With enormous potential for both consumers and industry, 5G is expected to roll out by 2020. From the next-generation radio access technology viewpoint, a step change in data speed and a significant reduction in end-to-end latency is a major concern for 5G, since the rapid development of the mobile Internet and the Internet of Things (IoT) exponentially accelerates the demand for high data–rate applications. In particular, many of the industry initiatives that have progressed with work on 5G declare that the network-level data rate in 5G should be 10-20 Gbps (that is, 10-20 times the peak data rate in 4G), and the user-experienced data rate should be 1 Gbps (100 times the user-experienced data rate in 4G). They also set the latency (end-to-end round-trip delay) at 1 millisecond (one-fifth of the latency in 4G).

The underlying physical connection in a cellular network is called radio access technology, which is implemented by a radio access network (RAN). A RAN basically utilizes a channel access technique to provide the mobile terminals with a connection to the core network. The design of a suitable multiple access technique is one of the most important aspects in improving the system capacity. Multiple access techniques can broadly be categorized into two different approaches [1], namely, orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA). An orthogonal scheme allows a perfect receiver to entirely separate unwanted signals from the desired signal using different basis functions. In other words, signals from different users are orthogonal to each other in orthogonal schemes. Time division multiple access (TDMA), and orthogonal frequency-division multiple access (OFDMA) are a couple of examples of OMA schemes. In TDMA, several users share the same frequency channel on a time-sharing basis. The users communicate in rapid succession, one after the other, each using their assigned time slots. OFDMA allows multi-user communications through an orthogonal frequency-division multiplexing (OFDM) technique in which subcarrier frequencies are chosen so that the subcarriers are orthogonal to each other. In contrast to OMA, NOMA allows allocating one frequency channel to multiple users at the same time within the same cell and offers a number of advantages, including improved spectral efficiency (SE), higher cell-edge throughput, relaxed channel feedback (only the received signal strength, not exact channel state information (CSI), is required), and low transmission latency (no scheduling request from users to base station is required). The available NOMA techniques can broadly be divided into two categories, namely, power-domain and code-domain NOMA. This paper focuses on the power-domain NOMA that superposes multiple users in power domain and exploits the channel gain difference between multiplexed users. At the transmitter side, signals from various users are superposed and the resulting signal is then transmitted over the same channels (i.e., the same time-frequency resources). At the receiver sides, multiuser detection (MUD) algorithms, such as successive interference cancellation (SIC) are utilized to detect the desired signals. Although this paper primarily surveys the power-domain superposition coding (SC)-based NOMA, a brief discussion of other classes of NOMA is given in the next section.

OMA is a realistic choice for achieving good performance in terms of system-level throughput. However, due to the aforementioned upcoming wave, 5G networks require further enhancement in system efficacy. In this regard, researchers all over the globe have started investigating NOMA as a promising multiple access scheme for future radio access. NOMA achieves superior spectral efficiencies by SC at the transmitter with SIC at the receiver [2, 3]. On the top of that, the evolution of wireless networks to 5G poses new challenges for energy efficiency (EE), since the entire network will be ultra-dense. With an extreme increase in the number of infrastructure nodes, total energy consumption may simply surpass an acceptable level. Although substantial energy is basically consumed by the hardware, NOMA has an inherent ability to adapt the transmission strategy according to the traffic and users' CSIs. Thus, it can achieve a good operating point, where both spectrum efficiency and EE become optimum.

Over the past few years, NOMA has attracted a great deal of attention from researchers trying to meet 5G requirements. As a consequence, many research efforts in this field already exist. Research trends in NOMA include diverse topics, for example, various performance analysis methods, fairness analysis, EE, and user pairing. Many researchers are attempting to further enhance the performance of other existing wireless technologies, such as cooperative communications, multiple-input multiple-output (MIMO), light communications, and relay networks by using NOMA. However, NOMA in 5G is still in its infancy.

BASIC CONCEPTS OF NOMA

There exist different NOMA solutions, which can primarily be classified into two major approaches. Fig. 2 presents a simple classification of the existing NOMA techniques. Unlike power-domain NOMA, which attains multiplexing in power domain, code-domain NOMA achieves multiplexing in code domain. Like the basic code division multiple access (CDMA) systems, code-domain NOMA shares the entire available resources (time/frequency). In contrast, code-domain NOMA utilizes user-specific spreading sequences that are either sparse sequences or non-orthogonal cross-correlation sequences of low correlation coefficient. This can be further divided into a few different classes, such as low-density spreading CDMA (LDS-CDMA) [4, 5], low-density spreading-based OFDM (LDS-OFDM) [6, 7], and sparse code multiple access (SCMA) [8, 9]. The use of low-density spreading sequences helps LDS-CDMA to limit the impact of interference on each chip of basic CDMA systems. LDS-OFDM can be thought of as an amalgamation of LDS-CDMA and OFDM, where the information symbols are first spread across low-density spreading sequences and the resultant chips are then transmitted on a set of subcarriers. SCMA is a recent code-domain NOMA technique based on LDS-CDMA. In contrast to LDS-CDMA, the information bits can be directly mapped to different sparse codewords, because both bit mapping and bit spreading are combined. When compared to LDS-CDMA,

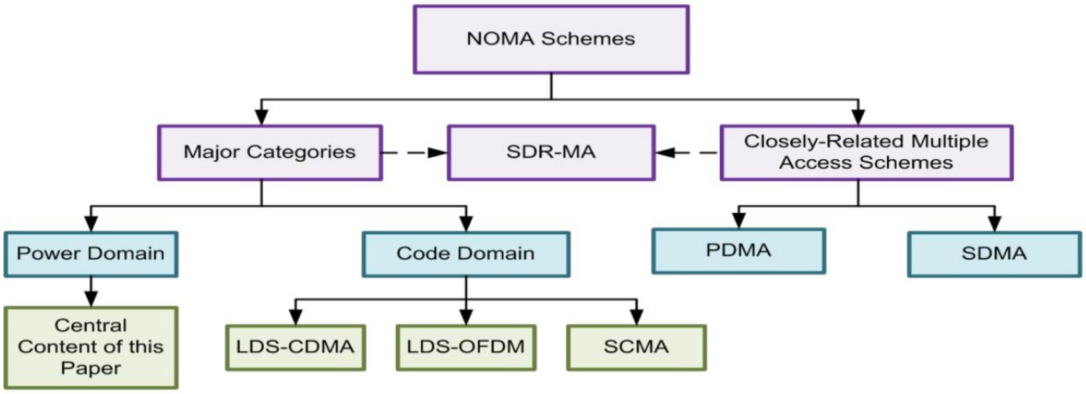

Fig. 2. A simple classification of NOMA techniques.

SCMA provides a low complexity reception technique and offers improved performances.

There exist some other multiple access techniques, which are also closely-related to NOMA, including pattern division multiple access (PDMA) [10] and spatial division multiple access (SDMA) [11, 12, 13, 14]. PDMA can be realized in various domains. At the transmitter side, PDMA first maximizes the diversity and minimizes the overlaps among multiple users in order to design non-orthogonal patterns. The multiplexing is then performed either in the code domain, spatial domain, or a combination of them. For SDMA, the working principle is inspired by basic CDMA systems. Instead of using user-specific spreading sequences, SDMA distinguishes different users by using user-specific channel impulse responses (CIRs). This technique is particularly useful for the cases where the number of uplink users is considerably higher than the number of corresponding receiving antennas in BS. However, accurate CIR estimation becomes challenging for a large number of users. The concept of software defined radio for multiple access (SDR-MA) allows various forms of NOMA schemes to coexist [15]. This technique provides a flexible configuration of participating multiple access schemes in order to support heterogeneous services and applications in 5G. It is worth noting that while the aforementioned list provides some insights into different forms of NOMA, it is not exhaustive, and the primary focus of this paper is on power-domain NOMA.

In the following, a brief note about SC and SIC is presented, since these two basic techniques play important roles in understanding the class of NOMA on which this paper focuses on. Henceforth, this paper refers to power-domain NOMA simply by NOMA.

POTENTIAL NOMA SOLUTIONS

This section presents an overview of the present and emerging NOMA research, in a categorized fashion, considered as potential solutions to problems or issues associated with the integration of NOMA in 5G. Detailed explanations and mathematical derivations of the techniques will be avoided, since our major focus is to cover the core ideas of the state-of-the-art NOMA research in 5G systems. Interested readers are referred to the original articles for greater depth.

A. Impact of Path Loss

A substantial number of researchers have investigated the performance of NOMA schemes to study the feasibility of adopting this technique as a multiple access scheme for 5G systems. A survey by Higuchi and Benjebbour and the references therein demonstrate that NOMA can be a promising power-domain user multiplexing scheme for future radio access [19]. In a cellular network with randomly deployed users, the path loss performance of NOMA can be evaluated under two situations. In the first scenario, each user has a targeted data rate determined by the assigned quality of service (QoS). Here, the outage probability is an ideal performance metric, since it measures the capability of NOMA to meet the users' QoS requirements. In the other scenario, users' rates are opportunistically allocated according to the channel conditions. In this situation, the achievable ergodic sum rate can be investigated to evaluate NOMA performance. According to Ding et al. [20], if users' data rates and assigned power are chosen properly, NOMA can offer better outage performance than other OMA techniques.

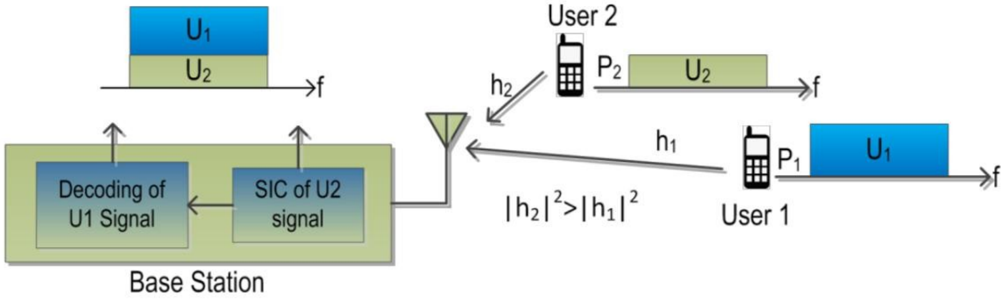

Fig. 2. NOMA in an uplink scenario.

According to the feedback framework of LTE, each user measures the downlink channel by employing reference signals and feeds back CSI in the form of predesigned transmission formats. This CSI feedback contains a rank indicator (RI), a precoding matrix indicator (PMI), and a channel quality indicator (CQI) [21]. Moreover, the rank is reported by each user at a certain time interval (i.e., semi-static). The BS can then use this feedback information for various purposes, including power control. During the channel measurement, full transmission power of BS and no interference from intra-cell users are considered by each user. On that, the reported RI is suitable for OMA. In case of NOMA, however, the transmission power is split between strong and weak users. Additionally, inter-user interference occurs in NOMA. Thus, both signal and interference powers experienced by NOMA users change, which may result in a different rank from that of reported RI assuming full transmission power. Therefore, the rank feedback in NOMA will inherently place a limitation on the achievable gain. A couple of rank optimization methods [21] could be deployed in order to overcome this

PERFORMANCE EVALUATIONS

To illustrate the performance gains, this section provides numerical results for various NOMA setups. Two primary performance metrics, namely, outage probability and achievable rate are considered for this purpose. Also, the section provides some insights into SE and EE performances of NOMA.

A. *Outage Probability*

limitation, thereby enhancing both the outage probability and ergodic capacity performance.

Based on (10), Fig. 3 compares the outage performance of a NOMA scheme with that of an OMA scheme for a cellular network comprising randomly deployed users with m. The users are uniformly located. The targeted data rates of 0.1 bits per channel use (BPCU) and 0.5 BPCU, respectively, for a weak user and a strong user (user 2) were used. Since the conventional orthogonal scheme is considered for benchmarking, its targeted rate is 0.6 BPCU (the addition of two users' data rates).

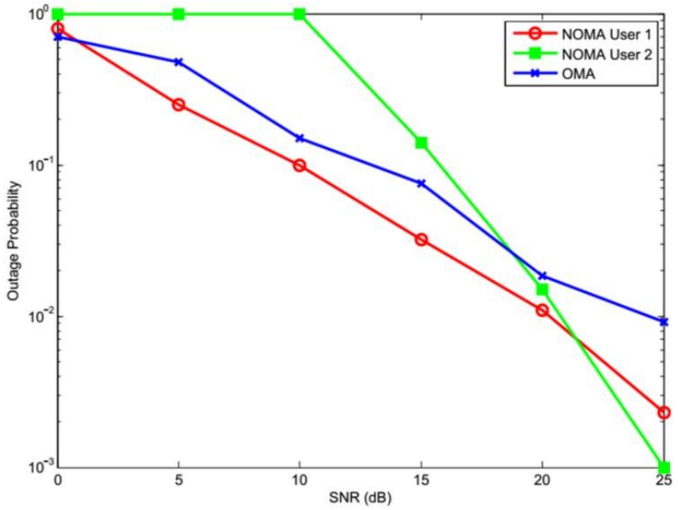

Fig. 3. Outage performance of NOMA in 5G with random users in a cell.

Fig. 4 demonstrates the performance of a typical MIMO NOMA system in terms of outage probability. This figure considers two clusters, where each cluster contains two users equipped with three antennas. The power allocation ratio is 1:4, and target data rates of the strong user and the weak user are 3 BPCU and 1.3 BPCU, respectively. The figure indicates that the MIMO NOMA system outperforms MIMO with OMA, particularly at high SNR values. By comparing the slopes of the performance curves, it can be concluded that the diversity gain of MIMO NOMA is the same as MIMO OMA.

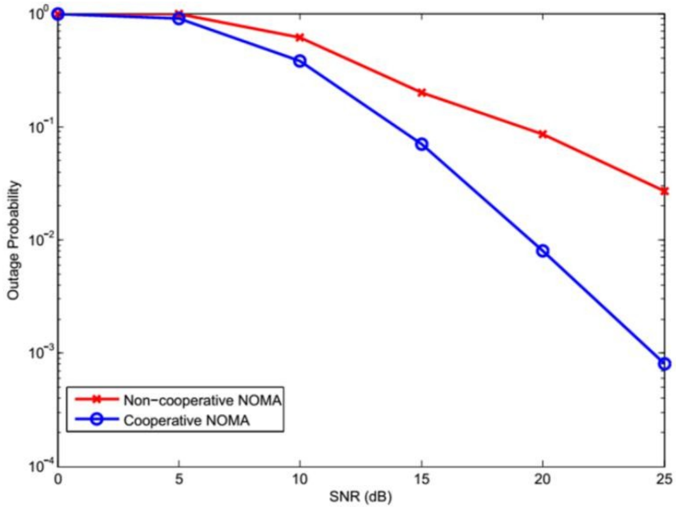

Fig. 4. Outage performance of a cooperative NOMA.

Fig. 5 shows the sum capacities of NOMA-BF (discussed in Section III. D) and conventional multi-user beamforming with a correlation threshold , system BW of 4.32 MHz, maximum transmission power per cluster at 43 dBm, and noise density of -169 dBm/Hz. As can be seen, NOMA-BF improves the sum capacity. Here, the users are randomly located with uniform distribution in a cell radius of 500 m.

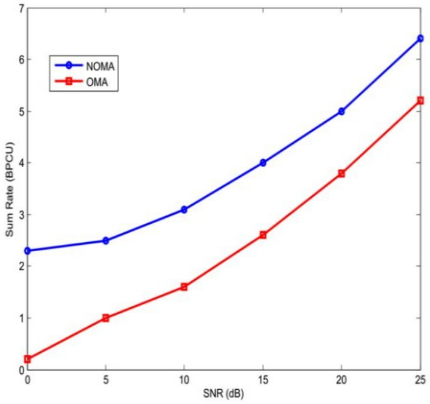

Fig. 5. Sum rate performance of NOMA in 5G with random users in a cell.

V. CONCLUDING REMARKS

This paper provides a comprehensive overview of the present and emerging power-domain SC-based NOMA research into 5G, and discusses NOMA performance with numerical results. It is clear that NOMA is a candidate multiple access technology for next-generation radio access. Its diversity gain originates from the power domain of the signals to be transmitted in a superposed fashion. Many research results have been found in favor of NOMA in terms of outage probability, achievable capacity, weak users' rate guarantees, and cell-edge user experiences. In addition to perfect SC at the transmitter and error-free SIC at the receiver, optimum power allocation, QoS-oriented user fairness, appropriate user pairing, and good link adaptation are also required to obtain the maximum benefits offered by NOMA. In addition, this paper discusses how NOMA works with various standard wireless technologies, including cooperative communications and MIMO. For a deeper understanding of NOMA, this paper provides a discussion on how inter-cell interference in a network can be mitigated, and explains how a trade-off between energy efficiency and bandwidth efficiency can be achieved. The discussions of several important issues, such as dynamic user pairing, distortion analysis, interference analysis, resource allocation, heterogeneous networks, carrier aggregation, and transmit antenna selection, are expected to facilitate, and provide a basis for, further research on NOMA in 5G. This paper offers a general view of some implementation issues, including computational complexity, error propagation, deployment environments, and standardization status. In sum, the results of this survey are expected to be useful to researchers working in the area of wireless communications and NOMA.

REFERENCES

[1] P. Wang, J. Xiao, and L. P "Comparison of orthogonal and non-orthogonal approaches to future wireless cellular systems," IEEE Veh. Technol. Mag., vol. 1, no. 3, pp. 4-11, Sep. 2006.

A. Benjebbour, Y. Saito, Y. Kishiyama, A. Li, A. Harada, and T. Nakamura, "Concept and practical considerations of non-orthogonal multiple access (NOMA) for future radio access," in Proc. Int. Symp.

Intelligent Signal Process. Commun. Syst. (ISPACS), Nov. 2013. pp. 770-774.

[2] D. Tse and P. Viswanath, Fundamentals of Wireless Communication. Cambridge, The UK: Cambridge University Press, 2005.

[3] R. Hoshyar, F. P. Wathan, and R. Tafazolli, "Novel low-density signaturefor synchronous CDMA systems over AWGN channel," IEEE Trans. Signal Process., vol. 56, no. 4, pp. 1616–1626, Apr. 2008.

[4] R. Razavi, R. Hoshyar, M. A. Imran, and Y. Wang, "Information theoretic analysis of LDS scheme,"

[5] IEEE Commun. Lett., vol. 15, no. 8,pp. 798–800, Jun. 2011.

[6] M. Al-Imari, P. Xiao, M. A. Imran, and R. Tafazolli, "Uplink nonorthogonalmultiple access for 5G wireless networks," in Proc. Int. Symposium on Wireless Commun. Syst. (ISWCS), Aug. 2014, pp. 781– 785.

[7] M. Al-Imari, M. A. Imran, and R. Tafazolli, "Low density spreading for next generation multicarrier cellular systems," in Proc. IEEE Int. Conf. Future Commun. Networks (ICFCN), Apr. 2012, pp. 52–57.

[8] H. Nikopour and H. Baligh, "Sparse code multiple access," in Proc. IEEE Int. Symposium on Personal Indoor and Mobile Radio Commun. (PIMRC), Sep. 2013, pp. 332–336.

[9] H. Nikopour, E. Yi, A. Bayesteh, K. Au, M. Hawryluck, H. Baligh, and J. Ma, "SCMA for downlink multiple access of 5G wireless networks," in Proc. IEEE Global Telecommun. Conf. (GLOBECOM), Dec. 2014, pp. 1–5.

[10] S. Kang, X. Dai, and B. Ren, "Pattern division multiple access for 5G," Telecommunications Network Technology, vol. 5, no. 5, pp. 43–47, May 2015.

[11] L. Hanzo , M. Munster , B. J. Choi, and T. Keller, OFDM and MC-CDMA for Broadband Multi-User Communications, WLANs and Broadcasting, The US: IEEE Press, 2003.

[12] T. Abe and T. Matsumoto, "Space-time turbo equalization in frequency-selective MIMO channels,"

[13] IEEE Trans. Veh. Technol., vol. 52, no. 3, pp. 469-475, May 2003.

[14] M. Y. Alias, S. Chen, and L. Hanzo, "Multiple-antenna-aided OFDM employing genetic-algorithm-assisted minimum bit error rate multiuser detection," IEEE Trans. Veh. Technol., vol. 54, no. 5, pp. 1713–1721, Sep. 2005.

[15] L. Hanzo, S. Chen, J. Zhang, and X. Mu, "Evolutionary algorithm assisted joint channel estimation and turbo multi-user detection/decoding for OFDM/SDMA," IEEE Trans. Veh. Technol., vol. 63, no. 3, pp. 1204–1222, Mar. 2014.

[16] L. Dai, B. Wang, Y. Yuan, S. Han, C. l. I and Z. Wang, “Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends,” IEEE Commun. Mag., vol. 53, no. 9, pp. 74-81, Sep. 2015.

[17] T. Cover, “Broadcast channels,” IEEE Trans. Inf. Theory, vol. 18, no. 1, pp. 2-14, Jan 1972.

[18] S. Vanka, S. Srinivasa, Z. Gong, P. Vizi, K. Stamatiou, and M. Haenggi, “Superposition coding strategies: Design and experimental evaluation,” IEEE Trans. Wireless Commun., vol. 11, no. 7, pp. 2628–2639, 2012.

[19] N. I. Miridakis and D. D. Vergados, “A survey on the successive interference cancellation performance for single-antenna and multiple-antenna OFDM systems,” IEEE Commun. Surveys Tutorials, vol. 15, no. 1, pp. 312-335, Feb. 2013.

[20] K. Higuchi and A. Benjebbour, “Non-orthogonal multiple access (NOMA) with successive interference cancellation,” IEICE Trans. Commun., vol. E98-B, no. 3, pp. 403-414, Mar. 2015.

[21] Z. Ding, Z. Yang, P. Fan, and H.V. Poor, “On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users,” IEEE Signal Process. Lett., vol. 21, no. 12, pp. 1501-1505, Dec. 2014.

[22] X. Chen, A. Benjebbour, Y. Lan, A. Li, and H. Jiang, “Impact of rank optimization on downlink non-orthogonal multiple access (NOMA) with SU-MIMO,” in Proc. IEEE Int. Conf. Commun. Syst. (ICCS), Nov. 2014, pp. 233-237.

A. S. Ibrahim, A. K. Sadek, W. Su, and K. J. R. Liu, “Cooperative communications with relay-selection: When to cooperate and whom to cooperate with,” IEEE Trans. Wireless Commun., vol. 7, no. 7, Jul. 2008.

[23] Z. Ding, M. Peng, and H. V. Poor, “Cooperative non-orthogonal multiple access in 5G systems,” IEEE Commun. Lett., vol. 19, no. 8, pp. 1462-1465, Aug. 2015.

[24] Y. Hayashi, Y. Kishiyama, and K. Higuchi, “Investigations on power allocation among beams in non-orthogonal access with random beamforming and intra-beam SIC for cellular MIMO downlink,” in Proc. IEEE Veh. Technol. Conf., Las Vegas, NV, USA, Sep. 2013.

[25] B. Kim, S. Lim, H. Kim, S. Suh, J. Kwun, S. Choi, C. Lee, S. Lee, and D. Hong, “Non-orthogonal multiple access in a downlink multiuser beamforming system,” in Proc. IEEE Military Commun. Conf., San Diego, CA, USA, Nov. 2013.