BER Performance Evaluation of Downlink MUSA over Rayleigh Fading Channel

Yao Xu, Gang Wang(✉), Liming Zheng, Rongkuan Liu, and Donglai Zhao

Harbin Institute of Technology, Harbin, China
xuyao_hit@sina.com,
{gwang51, zheng, liurongkuan}@hit.edu.cn,
zdl527@126.com

Abstract. Downlink multi-user shared access (MUSA) is a non-orthogonal multiple access scheme (NOMA) based on the traditional power domain superposition and uses a mirror constellation to optimize the modulated symbol mapping of the paired users. In this paper, bit error ratio (BER) performance of MUSA with successive interference cancellation (SIC) is investigated in a cellular downlink scenario over Rayleigh fading channel. Firstly, we elaborate downlink MUSA system based on NOMA and spreading sequences in detail. Then, we compare the BER performance of MUSA with pure NOMA under different power allocation schemes. On this basis, we further study the system average BER performance in downlink MUSA and NOMA with respect to the power difference of the users, respectively. In addition, BER performance of MUSA with different spreading sequences is evaluated. Finally, the simulation results show that MUSA with appropriate spreading sequences is able to obtain better BER performance than NOMA under the same simulation conditions, and a reasonable power allocation is the key to improve BER performance of MUSA and NOMA.

Keywords: MUSA · NOMA · SIC · BER performance · 5G communication Rayleigh fading channel

1 Introduction

The rapid growth of wireless communication technology and smart Internet of Things (IoT) brings many challenges to the fifth generation (5G) mobile communications, such as higher user experience rates, higher spectral efficiency, higher connection density, and lower handover latency, etc. To meet these requirements, enhanced or innovative technologies are required. A promising technology which can increase the system throughput and provide massive connections is non-orthogonal multi-user superposition and shared access among the potential candidates. Non-orthogonal access enables several users to utilize time and frequency resources through simple linear superposition or power domain multiplexing. At present, the non-orthogonal access schemes proposed by the industry and academia mainly include sparse code multiple access (SCMA) [1] technology based on multi-dimensional modulation and sparse

X. Gu et al. (Eds.): MLICOM 2017, Part I, LNICST 226, pp. 85–94, 2018.
https://doi.org/10.1007/978-3-319-73564-1_9

code spreading, patterning division multiple access (PDMA) [2] based on non-orthogonal feature pattern, non-orthogonal multiple access (NOMA) [3–11] based on power superposition, and multi-user shared access (MUSA) [12, 13] based on complex spreading sequence and enhanced superposition coding, etc.

In the past, the performance of NOMA has been evaluated in many research works. In [3], the authors discussed the outage performance and the ergodic sum rates of a downlink NOMA with randomly distributed users. The authors in [4] considered the outage probability and the ergodic sum rates of a NOMA based relay cooperative communication networks over Nakagami-m fading channels. For instance, the authors of [5] have provided an analysis of NOMA performance gains from both link-level and system-level perspectives. It has been shown that NOMA can provide higher gains compared to OFDMA. In [6], system-level throughput of a NOMA which assumes proportional fair based radio resource allocation and uses a successive interference canceller in the cellular downlink have been studied. In order to study a more realistic analysis of SIC in downlink NOMA, the study in [7] has given the numerical results in terms of BER when the receiver uses both perfect and imperfect SIC. In [8], a NOMA constellation rotation scheme has been proposed to enhance the link-level performance for NOMA with ML receiver, and the symbol error rate (SER) simulations have been conducted. For uplink NOMA, the authors in [9] proposed an uplink NOMA strategy that removes the resource allocation exclusivity to achieve higher capacity and provided the link-level performance evaluation in terms of BER. The work in [10] analyzes the uplink spectral efficiency of NOMA in Rayleigh fading environment. An uplink power control scheme has been developed for NOMA to achieve diverse arrived power in [11]. The outage performance and the achievable sum rate for the scheme proposed in this paper have been theoretically analyzed. Additionally, MUSA scheme has been first proposed in [12], and the authors studied the link-level and system-level performance in terms of block error rate (BLER) compared to orthogonal systems.

In this paper, we focus on downlink MUSA over Rayleigh fading channel with two goals. The first is to compare BER performance of MUSA with NOMA in a two users scenario when they use different power allocation strategies, and then investigate the relationship between BER performance and users' power difference. The second is to evaluate BER performance of MUSA using various spreading sequences in the downlink scenario. The numerical results derive that MUSA outperform NOMA in terms of BER performance under the same conditions.

2 System Model

2.1 Basic Notation

Consider a downlink transmission scenario in which a base station (BS) serving M randomly distributed single-antenna users, U_m, with $m \in \boldsymbol{M} = \{1, \ldots, M\}$. And we assume the total available transmitted power of the base station is P and the power allocation coefficient for m-th user is c_m, with $\sum_{m \in M} c_m = 1$. The channel between the user and the BS can be described as independent and identically distributed (i.i.d.) Rayleigh block flat fading with additive white Gaussian noise (AWGN) which is a random complex variable with zero mean and σ_n^2 variance. The channel coefficients and gains can be denoted by h_m (for BS $\rightarrow$ U_m link), and $|h_m|^2$, respectively. According to the Rayleigh fading property, h_m can be written as $h_m = v_m/\sqrt{1+d_m^\alpha}$, where v_m is the small-scale Rayleigh fading gains with $v_m \sim CN(0,\ \sigma_n^2)$, d_m denotes the distance between the BS and m-th user and α denotes the pass loss factor. Without loss of generality, we assume that $0 < |h_1|^2 \leq |h_2|^2 \leq \cdots \leq |h_m|^2$ and the power allocation coefficients should satisfy $c_1 \geq c_2 \geq \cdots \geq c_M$.

2.2 Principle of Downlink NOMA

The BS can make multi users share the same radio resources, either in time, frequency or code via the NOMA scheme, which uses superposition coding at the transmitter and SIC at the receiver. Based on the protocol of NOMA, ransmitted signal from the BS can be given as $x_{\text{NOMA}} = \sum_{i=1}^{M} \sqrt{c_i P} x_i$, where x_i denotes one information bit for m-th user. Therefore, the received signal at m-th user can be written by

$$y_{m,\text{NOMA}} = h_m \sum\nolimits_{i=1}^{M} \sqrt{c_i P} x_i + n_m \tag{1}$$

Where n_m denotes the Gaussian noise at receiver. SIC will be carried at m-th user receiver and the user can decode the information bits for i-th user with $i < m$. As a result, the user can remove all inter-user interference from the weaker users and its achievable data rate is given by

$$R_{m,\text{NOMA}} = \log\left(1 + \frac{c_m P |h_m|^2}{P|h_m|^2 \sum_{i=m+1}^{M} c_i + \sigma_n^2}\right) \tag{2}$$

2.3 Principle of Downlink MUSA

NOMA scheme based on power superposition allows the BS send a linear superposition of multi user's data flows directly in the power domain by using the same time-frequency resources. A reasonable power allocation strategy and user pairing should be considered to achieve good performance but a wrong choice of power allocation scheme will lead to greater multiple access interference. In order to make the SIC process at the receiver more robust, complex spreading sequences are used in downlink MUSA to ensure low correlation among users and improve system performance.

According to the principle of MUSA, the BS will send $\mathbf{x}_{\text{MUSA}} = \sum_{i=1}^{M} \sqrt{c_i P}(x_i \mathbf{w}_i)$, where $\mathbf{w}_{i(1 \times L)}$ denotes a short normalized complex spreading sequence with the size of L for i-th user. Therefore, the observation at m-th user is given by

$$\mathbf{y}_{m,\text{MUSA}} = h_m \sum\nolimits_{i=1}^{M} \sqrt{c_i P}(x_i \mathbf{w}_i) + \mathbf{n}_m \tag{3}$$

Similarly, each receiver also employs a SIC technique and the achievable data rate of m-th user is given by

$$\begin{aligned} R_{m,\mathrm{MUSA}} &= \log\left(1 + \frac{c_m P|h_m|^2 ||\mathbf{w}_m||^2}{P|h_m|^2 \sum_{i=m+1}^{M} c_i ||\mathbf{w}_i||^2 + \sigma_n^2}\right) \\ &= \log\left(1 + \frac{c_m P|h_m|^2}{P|h_m|^2 \sum_{i=m+1}^{M} c_i + \sigma_n^2}\right) \end{aligned} \tag{4}$$

In Fig. 1, a more specific transceiver structure for the BS to m-th user link is illustrated. And the detailed step descriptions are provided as follows.

Step1: The information bit flow $\mathbf{I}_i$ for i-th user is encoded using a turbo code with code rate R, and the output of encoder is coded bit vector $\mathbf{IC}_{i(1 \times N)}$, where N denotes the length of $\mathbf{IC}_m$.

Step2: $\mathbf{IC}_i$ is modulated by a QPSK modulator, generating the modulated symbols vector $\mathbf{ICM}_{i(1 \times N/2)}$.

Step3: $\mathbf{ICM}_i$ is spread with a short complex spreading sequence $\mathbf{w}_{i(1 \times L)}$, producing the spread symbols vector $\mathbf{ICMS}_{i(1 \times NL/2)}$.

Step4: $\mathbf{ICMS}_i$ is transmitted over Rayleigh fading channel.

Step5: At the receiver side, linear detection and SIC are used to decode the information bits for m-th user and the vector form of the received signal is given by

$$\mathbf{r}_{m,\mathrm{MUSA}} = h_m \sum_{i=1}^{M} \sqrt{c_i P}\,\mathbf{ICMS}_i + \mathbf{n}_m \tag{5}$$

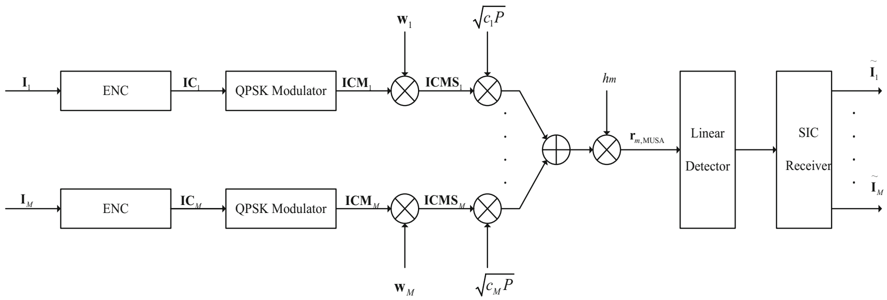

Fig. 1. Downlink MUSA system structure

3 Detection and Spreading Sequences

Compare with the spreading sequences used by traditional direct sequence CDMA, the modulated symbols of users are spread by specially designed complex spreading sequences which can promote the implementation of robust SIC. Additionally, detection algorithm at receiver is the key to ensure the good performance of downlink MUSA. This section is dedicated to the details of the complex spreading sequences design and minimum mean squared error based on SIC (MMSE-SIC) algorithm.

3.1 MMSE-SIC

One way to boost the performance of SIC receiver is to use in conjunction with liner detection algorithms such as zero forcing (ZF) and MMSE. For MMSE algorithm, the optimization goal is to minimize the mean squared error between the estimated values of transmit data based on received data and the target data, and the filter coefficient matrix of the linear detector can be described as following

$$\mathbf{W}_{\mathrm{MMSE}} = (\mathbf{H}^H\mathbf{H} + \sigma^2\mathbf{I})^{-1}\mathbf{H}^H \tag{6}$$

In addition, the SIC receiver performs data detection in descending order of users' signal to interference plus noise ratio (SINR). For the sake of analysis, the matrix form of Eq. (5) can be further expressed by

$$\begin{aligned}\mathbf{R}_{m,\mathrm{MUSA}} &= \sum\nolimits_{i=1}^{M} \sqrt{c_i P} h_m (\mathbf{w}_i^{\mathrm{T}} \times \mathbf{ICM}_i) + \mathbf{N} \\ &= \sum\nolimits_{i=1}^{M} \tilde{\mathbf{H}}_i \times \mathbf{ICM}_i + \mathbf{N}\end{aligned} \tag{7}$$

Where $\tilde{\mathbf{H}}_i = \sqrt{c_i P} h_m \mathbf{w}_i^{\mathrm{T}}$ is the equivalent channel coefficient matrix of i-th user. The steps of MMSE-SIC in downlink MUSA are summarized in Algorithm 1.

Algorithm 1 MMSE-SIC detection in downlink MUSA(for BS→m-th user link)

1: Initialize k, m, i, number of users M, SINR of i-th user $SINR_i$, detection coefficient matrix of i-th user ξ_i, ID of user with maximum $SINR$ j←0,estimated value of j-th user's modulated symbols $\hat{\mathbf{ICM}}_j$ and information bits $\hat{\mathbf{I}}_j$, encoding and modulation operator $\mathbf{Q}$(.), de modulation and decoding operator $\mathbf{Q}^{-1}$(.), set of user IDs U={1,2,…,M}.

2:**while** $j \neq m$ **do**

3: $\forall i \in U$, compute $\xi_i = (\tilde{\mathbf{H}}_i^H \tilde{\mathbf{H}}_i + \sigma^2\mathbf{I})^{-1} \tilde{\mathbf{H}}_i^H$, $SINR_i = \dfrac{\| \tilde{\mathbf{H}}_i \xi_i \|^2}{\| \tilde{\mathbf{H}}_i \|^2 \sum_{k \in U, k \neq i} \| \xi_k \|^2 + N_i}$

4:Search user ID with maximum $SINR$, $\max_{i \in U}\{SINR_i\} = SINR_j, j \in U$

5:Compute $\hat{\mathbf{ICM}}_j = \xi_i \mathbf{R}_{m,\mathrm{MUSA}}$, $\hat{\mathbf{I}}_j = \mathbf{Q}^{-1}(\hat{\mathbf{ICM}}_j)$

6:Update $\mathbf{R}_{m,\mathrm{MUSA}} = \mathbf{R}_{m,\mathrm{MUSA}} - \sqrt{c_i P}\mathbf{H}_m(\mathbf{W}_j \times \mathbf{Q}(\hat{\mathbf{I}}_j))$, U=U-{j}

7:**end**

8: $\hat{\mathbf{I}}_m \leftarrow \hat{\mathbf{I}}_j$

9:**Return**: $\hat{\mathbf{I}}_m$

3.2 Spreading Sequences Design

The complex spreading sequences used by downlink MUSA is the same as that used in uplink MUSA. The design of short complex spreading sequences can not only achieve the low correlation between the user data but reduce the complexity of transceiver. The complex spreading sequences consists of a series of complex values in which the real and imaginary parts are taken from the same set including multiple real numbers. The available number of q-ary complex codes with the code length of L is q^{2L}. For instance, the complex spreading sequence constellations with $q = 2$ and $q = 3$ are shown in the Fig. 2, and each complex value of the spreading sequences corresponds to the point on the constellations.

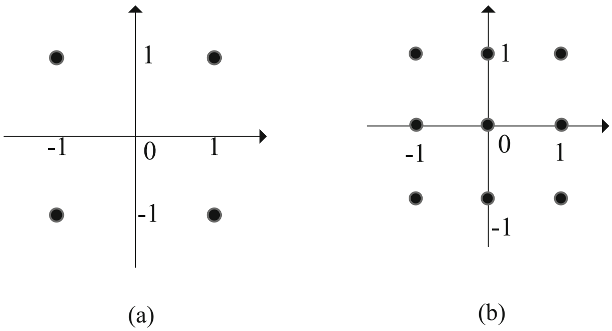

Fig. 2. Complex spreading sequence. (a) $q = 2$. (b) $q = 3$.

4 Numerical Results

For the sake of simplicity, numerical results are provided to explain the BER performance of downlink MUSA and NOMA in a two users scenario. In addition, we assume that UE_1 is the near user, UE_2 denotes the far user and power allocation difference between UE_1 and UE_2 is $\Delta P = c_2 - c_1$. The detailed parameters of simulation are summarized in Table 1.

Table 1. Simulation parameters

Parameters	Assumptions
Coding scheme	Turbo coding with code rate 1/2
Modulation scheme	QPSK
spreading sequences	PN codes, binary and tri-level complex spreading sequences
Transmitted power	$P = 1$
Power allocation scheme	Fixed power allocation algorithm, $c_1 + c_2 = 1$
Channel condition	Non-frequency selective and slow fading Rayleigh channel, $\alpha = 2$
Antenna configuration	1Tx, 1Rx
Channel estimation	Ideal
Cellular radius	$R_D < 30$ m
Receiver	MMSE-SIC

Figure 3 demonstrates the BER performance of near user with different power allocation schemes in downlink NOMA and MUSA. And the length of tri-level complex spreading sequence used in MUSA scheme is 4. As expected, the BER performance of MUSA is better than NOMA under the same conditions. Interestingly, the BER performance of NOMA becomes better firstly and then turn into worse with the increase of c_1, because BER of UE_1 is jointly decided by c_1 and ΔP., BER of NOMA decreases with the increase of UE_1's power when c_1 is less than 0.25, but when the c_1 is greater than 0.25, the power difference becomes smaller, which makes cross-correlation between users larger and results in higher bit error rates. However, the complex spreading sequences are used in MUSA to ensure the low cross-correlation between users so good BER performance is able to be obtained even if ΔP is small.

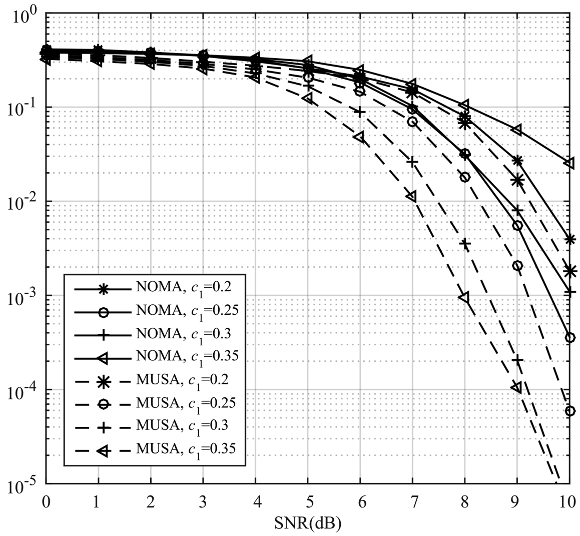

Fig. 3. BER performance comparison of UE_1.in downlink MUSA and NOMA

For a clearer explanation of the results in Figs. 3, 4 shows the relationship between the system average BER performance and the power allocation difference in downlink MUSA and NOMA scenario, respectively. And we assume SNR at UE_1 side is 12 dB and SNR at UE_2 is 8 dB. From the numerical results, it can be showed that the trend of system BER curves go down at first and then rise as well as UE_1, and the performance of UE_2 becomes better continuously with the increase of ΔP. The reason is that ΔP is the main influencing factor of UE_1's BER performance when ΔP is small, but c_1 becomes the main influence when c_1 is small enough. Additionally, BER of NOMA and MUSA becomes almost the same when c_1 is extremely small. Therefore, reasonable selection of power allocation scheme for downlink MUSA and NOMA is significant to gain good BER performance.

Figure 5 compares the BER performance of UE1 in downlink MUSA with various lengths of binary complex spreading sequences. As can be seen, the BER performance of receiver with different lengths binary spreading sequences are almost the same when the size of sequence is more than 8. However, BER performance is improved as the sequence length increase when the length of binary spreading sequence is less than 8. It is because longer spreading sequences can guarantee lower cross-correlation between users so that superior BER performance can be obtained by using longer complex spreading sequences when the length of sequences is not very long.

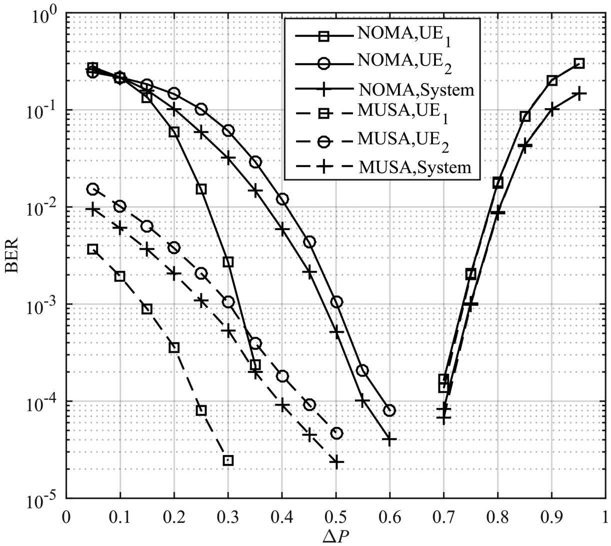

Fig. 4. Relationship between BER performance and users' power difference

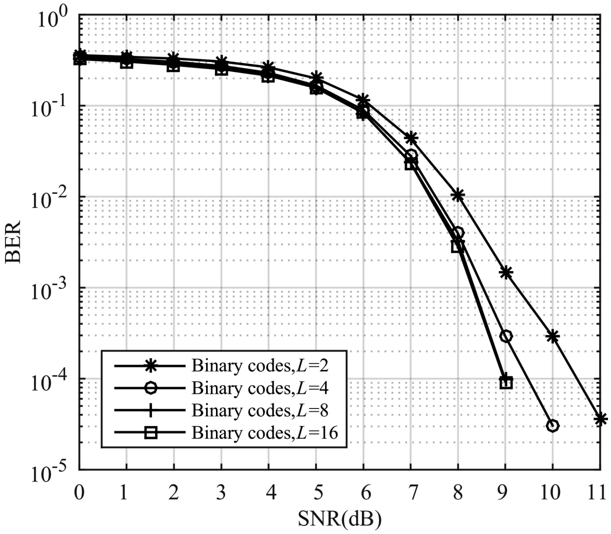

Fig. 5. BER performance of MUSA with different code length

As shown in Fig. 6, BER performance of downlink MUSA with various kinds of spreading sequences such as PN codes, binary complex spreading sequences and tri-level complex spreading sequences. We can find that complex spreading sequences are used in downlink MUSA, especially tri-level spreading sequences, can obtain better system BER performance compared with the PN codes. Because the cross-correlation between complex spreading sequences is lower than PN codes.

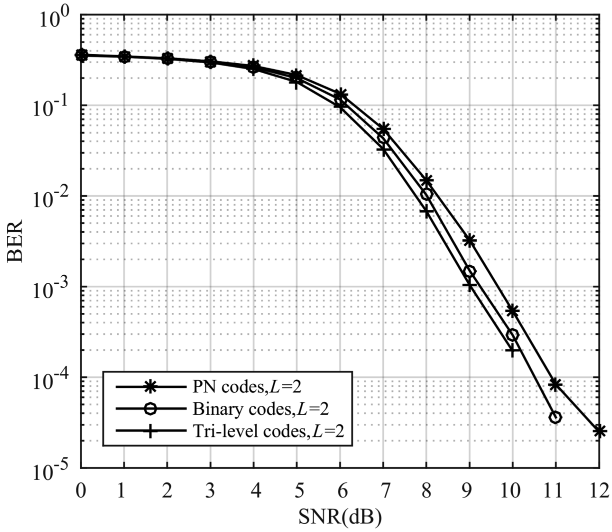

Fig. 6. BER performance of MUSA with different spreading sequences

5 Conclusion

In this paper, we have first proved that downlink MUSA can achieve better BER performance than NOMA over Rayleigh fading channel. Additionally, we have shown that system BER is a concave function of power difference in downlink MUSA and NOMA with two users, therefore the power allocation scheme should be chosen carefully to ensure their performance. And we have found great performance can be obtained by utilizing tri-level complex spreading sequences in downlink MUSA compared with binary PN codes. However, analysis for error propagation of SIC receiver and implementation complexity of MUSA is subject to further study.

Acknowledgement. This work is supported in part by National Natural Science Foundation of China (No. 61671184, No. 61401120, No. 61371100) and National Science and Technology Major Project of China (No. 2015ZX03001041).

References

1. Yan, C., Kang, G., Zhang, N.: A dimension distance-based SCMA codebook design. IEEE Access **5**, 5471–5479 (2017)
2. Chen, S., Ren, B., Gao, Q., Kang, S., Sun, S., Niu, K.: Pattern division multiple access-a novel nonorthogonal multiple access for 5th-generation radio networks. IEEE Trans. Veh. Technol. **66**(4), 3185–3196 (2017)
3. Ding, Z., Yang, Z., Fan, P., Poor, H.V.: On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users. IEEE Sig. Process. Lett. **21**(12), 1501–1505 (2014)
4. Men, J., Ge, J., Zhang, C.: Performance analysis of nonorthogonal multiple access for relaying networks over Nakagami-m fading channels. IEEE Trans. Veh. Technol. **66**(2), 1200–1208 (2017)
5. Benjebbour, A., Saito, K., Li, A., Kishiyama, Y., Nakamura, T.: Nonorthogonal multiple access (NOMA): concept, performance evaluation and experimental trials. In: 10th IEEE International Conference on Wireless Networks and Mobile Communications, pp. 1–6. IEEE Press, Morocco (2015)
6. Otao, N., Kishiyama, Y., Higuchi, K.: Performance of non-orthogonal access with SIC in cellular downlink using proportional fair-based resource allocation. In: 9th IEEE International Symposium on Wireless Communication Systems, pp. 476–480. IEEE Press, Paris (2012)
7. Usman, M.R., Khan, A., Usman, M.A., Seong, J.Y., Shin, S.Y.: Performance of perfect and imperfect SIC in downlink non orthogonal multiple access (NOMA). In: 2016 IEEE International Conference on Smart Green Technology in Electrical and Information Systems, pp. 102–106. IEEE Press, Bali (2016)
8. Zhang, J., Wang, X., Tsuyoshi, H., Tokuro, K.: Downlink non-orthogonal multiple access (NOMA) constellation rotation. In: IEEE 84th Vehicular Technology Conference, pp. 1–5. IEEE Press, Montreal (2016)
9. Mohammed, A., Pei, X., Mohammed, A.I., Rahim, T.: Uplink non-orthogonal multiple access for 5G wireless networks. In: 11th IEEE International Symposium on Wireless Communication Systems, pp. 781–785. IEEE Press, Barcelona (2014)
10. Pongsatorn, S., Tatcha, C.: Uplink spectral efficiency for non-orthogonal multiple access in Rayleigh Fading. In: 18th IEEE International Conference on Advanced Communication Technology, pp. 751–754. IEEE Press, Pyeongchang (2016)
11. Zhang, N., Wang, J., Kang, G., Liu, Y.: Uplink nonorthogonal multiple access in 5G systems. IEEE Commun. Lett. **20**(3), 458–461 (2016)
12. Yuan, Z., Yu, G., Li, W., Yuan, Y., Wang, X., Xu, J.: Multi-user shared access for internet of things. In: IEEE 83rd Vehicular Technology Conference, pp. 1–5. IEEE Press, Nanjing (2016)
13. Yuan, Y., Yuan, Z., Yu, G., Hwang, C., Liao, P., Li, A., Takeda, K.: Non-orthogonal transmission technology in LTE evolution. IEEE Commun. Mag. **54**(7), 68–74 (2016)