Performance Analysis and Relay Selection of D2D Aided Cooperative NOMA System

Shuting Wu, Yucheng He, Yu Zhang, Yan Zhang, and Lin Zhou

Abstract This paper investigates a cooperative non-orthogonal multiple access (NOMA) network, where cell center users (CU) can directly communicate with base stations (BS), while cell edge users (EU) needs to have half-duplex relay to assist in transmission. Specially, a D2D communication link from relay to CU is designed, which fully exploits the spectral resource to transmit a new signal. In addition, a two-stage relay selection strategy (TSRS) is proposed, which maximizes the probability of CU's successful decoding under the premise of ensuring reliable reception of the EU. To evaluate the proposed D2D aided cooperative relaying using NOMA (DC-NOMA) scheme, exact outage probabilities of each user data are derived and confirmed by Monte-Carlo computer simulations. By analyzing the outage probability, the performance of the proposed DC-NOMA using the TSRS outperforms that of the partial relay selection scheme (PRSS). In particular, the increase in the number of relays can effectively improve the outage performance of the proposed DC-NOMA using the TSRS network.

1 Introduction

With the explosive growth of Internet of Things (IoT) devices and user services, future wireless communications network will face major challenges in high spectral efficiency, low latency and massive connectivity [1]. Against this background, a key technology for next-generation cellular communications is NOMA since it allows multiple users to allocate different power domains by sharing the same frequency/time/code resources [2, 3]. Many researchers are dedicated to studying

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L. C. Jain et al. (eds.), *Advances in Wireless Communications and Applications*,
Smart Innovation, Systems and Technologies 299,
https://doi.org/10.1007/978-981-19-2255-8_4

NOMA integrated with existing advanced schemes such as cooperative relaying system (CRS) [4], device-to-device (D2D) [5] and cognitive radio (CR) [6].

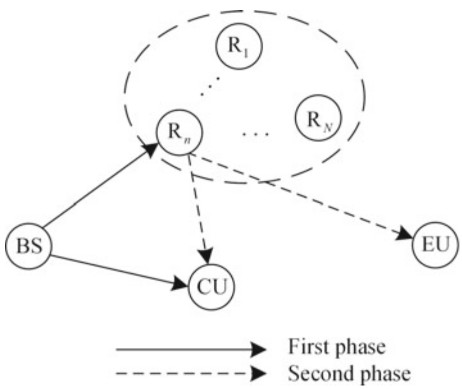
Relay technology is widely used in modern wireless communication networks because of its advantages in effectively expanding network coverage and improving communication reliability. Reference [7] studies a downlink full-duplex relay system using NOMA and considers the influence of self-interference factor on the system outage probability. D2D communication has now attracted intensive attention due to it can improve the local spectral efficiency. The key idea of D2D is to allow direct communication between two adjacent devices without a base station (BS) involved [8]. The work in [9] proposes cooperative D2D communication with multiple D2D pairs, and optimal power allocation is obtained. A D2D-aided C-NOMA (DC-NOMA) was presented in [10] to enhance the outage performance of the EU link using NOMA. An appropriate power allocation factor is selected, the ergodic sum capacities of DC-NOMA becomes better than C-NOMA and C-OMA [11].

Considering the multi-user relay system, the diamond-like relay selection model is studied [12]. On the basis of the max–min scheme, performance analysis of two relay modes are carried out: amplify-and-forward (AF) and decode-and-forward (DF). The simulation results show that DF relay performs better than AF relay. In addition, the relay selection scheme can further improve the performance of DC-NOMA. In the cooperative DF relay system using NOMA, PRSS is used in literature [13] and system outage performances are improved. In DC-NOMA system, this letter proposes a TSRS and PRSS, and the outage probability of closed-form expression are derived for each user data information.

2 System Model

It was illustrated in Fig. 1, a DC-NOMA network consisting of a base station (BS), a EU, a CU, and N relays $R_n (n = 1, ..., N)$ is considered in this paper. Due to the path loss, there is no direct link between BS and EU. Thus, BS needs send

Fig. 1 A DC-NOMA system model



information to EU helped by N DF relays. In return, the relay can directly send itself signal to CU via D2D communication. All channels are Rayleigh fading, the channel coefficients between BS $\rightarrow$ R$_n$, BS $\rightarrow$ CU, R$_n$ $\rightarrow$ EU and R$_n$ $\rightarrow$ CU are represented as h_{sn}, h_{sc}, h_{ne} and h_{nc}, variances are expressed as λ_{ij} and zero mean, where $ij \in \{sn, sc, ne, nc\}$. Moreover, noise model of receiver is complex additive white Gaussian noise (AWGN).

In the first phase, BS sends a superimposed signal $\sqrt{P_s a_1} x_e + \sqrt{P_s a_2} x_c$, where x_e and x_c denote the signal required by EU and CU, respectively. P_s denotes the total transmit power of BS, and the a_i denotes the power allocation coefficient, satisfied $a_2 < a_1$, where $a_1 + a_2 = 1$. Therefore, the received signals at CU and the relay are respectively given by

$$y_{s\rightarrow n} = h_{sn}(\sqrt{P_s a_1} x_e + \sqrt{P_s a_2} x_c) + n_n \tag{1}$$

$$y_{s\rightarrow c} = h_{sc}(\sqrt{P_s a_1} x_e + \sqrt{P_s a_2} x_c) + n_c \tag{2}$$

where n_c and n_n denote the additive white Gaussian noise with σ^2 variance at CU and the relay. According to NOMA principle, the decoding signal-to-interference-plus-noise ratio (SINR) can be expressed by

$$\gamma_{sc,x_e} = \frac{a_1 |h_{sc}|^2}{a_2 |h_{sc}|^2 + 1/\rho} \tag{3}$$

where $\rho = P_s/\sigma^2$ is the transmit signal-to-noise ratio (SNR). Perform SIC on the CU and SNR with signal x_c written as

$$\gamma_{sc,x_c} = \rho |h_{sc}|^2 a_2 \tag{4}$$

Besides, the side information obtained by the CU through decoding is used.

In the second phase, when the relay forwards the decoded signal, it also sends its own signal to the D2D receiver (i.e., CU). Suppose that an optimal relay R$_n$ is selected from N relays, this part will be discussed in Sect. 3. The DC-NOMA allows R$_n$ applies the superposition coding technique to combine two independent signals $\sqrt{P_d b_1} x_e + \sqrt{P_d b_2} x_d$, where x_e is intended message to EU and x_d is a D2D signal intended to CU. What's more, b_1 and b_2 are the power allocation factor, assumed as $b_1 = a_1, b_2 = a_2$ and P_d denotes the transmitted power of R$_n$, where $P_d = \eta P_s$. Thus, the received signals at EU and CU are represented by

$$y_{n\rightarrow e} = h_{ne}(\sqrt{P_d b_1} x_e + \sqrt{P_d b_2} x_d) + n_e \tag{5}$$

$$y_{n\to c} = h_{nc}\left(\sqrt{P_d b_1}x_e + \sqrt{P_d b_2}x_d\right) + n_c \tag{6}$$

where n_e and n_c denote the AWGN at CU and the relay, respectively.

After evaluating the channel information h_{nc}, use the side information x_e obtained in SIC to eliminate the interference signal $h_{nc}\sqrt{P_d b_1}x_e$ from $y_{n\to c}$. Therefore, the CU can decode the signal x_d without interference, and its SINR can be indicated as:

$$\gamma_{nc,x_d} = \rho_d |h_{nc}|^2 b_2 \tag{7}$$

3 Relay Selection Scheme

3.1 *Two-Stage Relay Selection*

This relay selection scheme is usually divided into two stages. The TSRS scheme proposed in this paper selects the relay that maximizes the quality of data transmitted by the CU under the premise of ensuring the reliable reception of the signal by the EU. In the first stage, in order to ensure the reliable transmission of EU, a relay set of successfully decoded signals is established:

$$S_r = \left\{n : 1 \le n \le N, \gamma_{sn,x_e} \ge \gamma_E^{th}, \gamma_{ne,x_e} \ge \gamma_E^{th}\right\} \tag{8}$$

where $\gamma_E^{th} \triangleq 2^{2R_e} - 1$, and R_e is the target threshold for signal x_e.

It is worth noting that, whether x_c can be successfully decoded only related to the BS $\to$ CU link. Therefore, the relay selection scheme will not enhance the outage performance of x_c. In other words, it is only necessary to consider maximizing the probability of successful decoding x_d in the second stage. Select the relay n^* with the best $\mathrm{R}_n \to$ CU link channel state information in the relay subset:

$$n^* = \arg\max_n \left\{|h_{nc}|^2, n \in S_r\right\} \tag{9}$$

Next, the outage probability of the TSRS is derived to further analyze the system performance. According to formula (8), it can be seen that EU failed to decode successfully x_e, only when $|S_r| = 0$. Thus, the outage probability (OP) on the EU can be evinced as:

$$
\begin{aligned}
P_{x_e}^{out,\mathrm{I}} &= \mathrm{P}[|S_r| = 0] \\
&= \prod_{n=1}^{N} \left(1 - \mathrm{P}\left[\gamma_{sn,x_e} \geq \gamma_E^{th}, \gamma_{ne,x_e} \geq \gamma_E^{th}\right]\right) \\
&= \prod_{n=1}^{N} \left(1 - \mathrm{P}\left[|h_{sn}|^2 \geq \frac{\Gamma_E^{th}}{\rho}\right]\mathrm{P}\left[|h_{ne}|^2 \geq \frac{\Gamma_E^{th}}{\rho_d}\right]\right) \\
&= \left(1 - e^{-\frac{\varphi_n}{\rho}}\right)^N
\end{aligned} \tag{10}
$$

where $\Gamma_E^{th} \triangleq \gamma_E^{th}/(a_1 - \gamma_E^{th} a_2)$ satisfied as $a_1 - \gamma_E^{th} a_2 > 0$, and $\varphi_n \triangleq \frac{\Gamma_E^{th}}{\lambda_{sn}} + \frac{\gamma_E^{th}}{\lambda_{ne}\eta}$ $(\forall n \in N)$.

Since an outage event occurs when CU cannot decode successfully x_e or x_c, the OP can be derived as

$$
\begin{aligned}
P_{x_c}^{out,\mathrm{I}} &= \mathrm{P}\left[\gamma_{sc,x_e} < \gamma_E^{th} \cup \gamma_{sc,x_c} < \gamma_C^{th}\right] \\
&= 1 - \mathrm{P}\left[\gamma_{sc,x_e} \geq \gamma_E^{th} \cap \gamma_{sc,x_c} \geq \gamma_C^{th}\right] \\
&= 1 - \mathrm{P}\left[|h_{sc}|^2 \geq \frac{\Gamma_E^{th}}{\rho} \cap |h_{sc}|^2 \geq \frac{\gamma_C^{th}}{\rho a_2}\right] \\
&= 1 - e^{-\frac{1}{\rho \lambda_{sc}} \max\left\{\Gamma_E^{th}, \frac{\gamma_C^{th}}{a_2}\right\}}
\end{aligned} \tag{11}
$$

An outage event occurs at CU when: (i) $|S_r| = 0$, no relay is selected to send D2D signal x_d; and (ii) $|S_r| > 0$, CU cannot successfully decode x_e or x_d. Hence, the outage probability of x_d at CU can be formulated as

$$
\begin{aligned}
P_{x_d}^{out} &= \mathrm{P}[|S_r| = 0] + \mathrm{P}\left[|S_r| > 0, \gamma_{sc,x_e} < \gamma_E^{th} \cup \gamma_{n^*c,x_d} < \gamma_D^{th}\right] \\
&= \mathrm{P}[|S_r| = 0] + \sum_{l=1}^{N} \mathrm{P}[|S_r| = l] \\
&\quad \mathrm{P}\left[\gamma_{sc,x_e} < \gamma_E^{th} \cup \gamma_{n^*c,x_d} < \gamma_D^{th} \,\middle|\, |S_r| = l\right]
\end{aligned} \tag{12}
$$

Since the channel gain satisfied the exponential distribution, according to the knowledge of probability theory, formula (12) can be divided into the following parts:

$$\begin{aligned}
\mathrm{P}[|S_r| = l] &= \binom{N}{l} \prod_{n=1}^{N-l} (1 - \mathrm{P}[\gamma_{sn,x_e} \geq \gamma_E^{th}, \gamma_{ne,x_e} \geq \gamma_E^{th}]) \\
&\quad \times \prod_{n=N-l+1}^{N} \mathrm{P}[\gamma_{sn,x_e} \geq \gamma_E^{th}, \gamma_{ne,x_e} \geq \gamma_E^{th}] \\
&= \binom{N}{l} \left[1 - e^{-\frac{\varphi_n}{\rho}}\right]^{N-l} e^{-\frac{\varphi_n}{\rho} l}
\end{aligned} \tag{13}$$

$$\mathrm{P}[(\gamma_{sc,x_e} < \gamma_E^{th} \cup \gamma_{n^*c,x_d} < \gamma_D^{th}) || S_r| = l] = \left[1 - e^{-\frac{\Gamma_E^{th}}{\rho \lambda_{sc}}} e^{-\frac{\gamma_D^{th}}{\rho_d a_2 \lambda_{nc}}}\right]^l \tag{14}$$

In summary, the closed-form expression for the outage probability of CU can be obtained as

$$\begin{aligned}
\mathrm{P}_{x_d}^{out,\mathrm{I}} &= \mathrm{P}[|S_r| = 0] + \mathrm{P}[|S_r| > 0, \gamma_{sc,x_e} < \gamma_E^{th} \cup \gamma_{n^*c,x_d} < \gamma_D^{th}] \\
&= \mathrm{P}[|S_r| = 0] + \sum_{l=1}^{N} \mathrm{P}[|S_r| = l] \mathrm{P}[(\gamma_{sc,x_e} < \gamma_E^{th} \cup \gamma_{n^*c,x_d} < \gamma_D^{th}) || S_r| = l] \\
&= (1 - e^{-\frac{\varphi_n}{\rho}})^N + \sum_{l=1}^{N} \binom{N}{l} \left[1 - e^{-\frac{\varphi_n}{\rho}}\right]^{N-l} e^{-\frac{\varphi_n}{\rho} l} \left[1 - e^{-\frac{\Gamma_E^{th}}{\rho \lambda_{sc}}} e^{-\frac{\gamma_D^{th}}{\rho_d a_2 \lambda_{nc}}}\right]^l
\end{aligned} \tag{15}$$

3.2 Partial Relay Selection

The PRSS selects the best relay based on the channel quality of BS to the relay link, which can be expressed as

$$n^* = \arg\max_{n} \{|h_{sn}|^2, n \in N\} \tag{16}$$

According to the principle of relay selection, the probability density function of $|h_{sn}|^2$ can be defined as

$$f_{|h_{sn}|^2}(x) = \sum_{n=1}^{N} \binom{N}{n} (-1)^{n-1} \frac{n}{\lambda_{sn}} e^{-\frac{n}{\lambda_{sn}} x} \tag{17}$$

Hence, the outage probability of x_e at EU can be formulated as

$$\begin{aligned}
\mathrm{P}_{x_e}^{out,\mathrm{II}} &= 1 - \mathrm{P}\left[\gamma_{sn,x_e} \ge \gamma_E^{th}, \gamma_{ne,x_e} \ge \gamma_E^{th}\right] \\
&= 1 - \mathrm{P}\left[|h_{sn}|^2 \ge \frac{\Gamma_E^{th}}{\rho}\right]\mathrm{P}\left[|h_{ne}|^2 \ge \frac{\Gamma_E^{th}}{\rho_d}\right] \\
&= 1 - \sum_{n=1}^{N}\binom{N}{n}(-1)^{n+1}e^{-\frac{n\Gamma_E^{th}}{\rho\lambda_{sn}}}e^{-\frac{\Gamma_E^{th}}{\rho_d\lambda_{ne}}}
\end{aligned} \tag{18}$$

The OP of x_d at CU can be derived by

$$\begin{aligned}
\mathrm{P}_{x_d}^{out,\mathrm{II}} &= 1 - \mathrm{P}\left[\gamma_{sn,x_e} \ge \gamma_E^{th} \cap \gamma_{nc,x_d} \ge \gamma_D^{th} \cap \gamma_{sc,x_e} \ge \gamma_E^{th}\right] \\
&= 1 - \mathrm{P}\left[|h_{sn}|^2 \ge \frac{\Gamma_E^{th}}{\rho} \cap |h_{nc}|^2 \ge \frac{\gamma_D^{th}}{\rho_d b_2} \cap |h_{sc}|^2 \ge \frac{\Gamma_E^{th}}{\rho}\right] \\
&= 1 - \left[\sum_{n=1}^{N}\binom{N}{n}(-1)^{n+1}e^{-\frac{n\Gamma_E^{th}}{\rho\lambda_{sn}}} \times e^{-\frac{\gamma_D^{th}}{\rho_d b_2\lambda_{nc}}} \times e^{-\frac{\Gamma_E^{th}}{\rho\lambda_{sc}}}\right]
\end{aligned} \tag{19}$$

Furthermore, the outage probability of x_c has nothing to do with the relay selection, so $\mathrm{P}_{x_c}^{out,\mathrm{II}} = \mathrm{P}_{x_c}^{out,\mathrm{I}}$.

4 Performance Analysis

To confirm and compare the outage performance analysis, numerical results are provided in this section. Aiming at the proposed TSRS DC-NOMA network, Monte-Carlo computer simulation is carried out in a Rayleigh fading channel. Unless otherwise specified, the proposed system simulation parameters are set by default as: normalized distance $d_{sc} = d_{sn} = 0.6$, $d_{ne} = 0.4$, $d_{nc} = 0.25$.We consider the fixed power allocation factors, $a_1 = b_1 = 0.65$ and $a_2 = b_2 = 0.35$. Besides, the pass loss exponent are set as $a_{sc} = a_{sn} = a_{ne} = a_{nc} = 3$, and $\eta = 0.5$. Without loss of generality, $R_e = 0.7$bit/s, $R_c = 0.4$bit/s, and $R_d = 0.4$bit/s denote the target rate.

Figures 2 and 3 show the outage probability of x_e and x_d under the PRSS and TSRS relay selection schemes versus SNR, respectively. It can be clearly observed that analytical curves match with simulation results. It is worth noting that compared to the PRSS scheme, the proposed TSRS scheme can significantly improve the outage performance of x_e and x_d. For the x_e, the PRSS scheme only selects the relay with the best BS to the relay link quality, and only guarantees the outage probability of successful decoding x_e at the relay. However, the proposed TSRS in this paper is based on the premise of ensuring successful decoding on the relay and EU. For the signal x_d, the reason is that the TSRS scheme selects the relay with the best $\mathrm{R}_n \rightarrow$ CU link quality under guarantee the reliable reception of the relay, which significantly reduces the OP of x_d.

Figure 4 illustrates how the number of relays affect outage probability of TSRS and PRSS scheme. Observe that the OP of PRSS scheme remains unchanged when

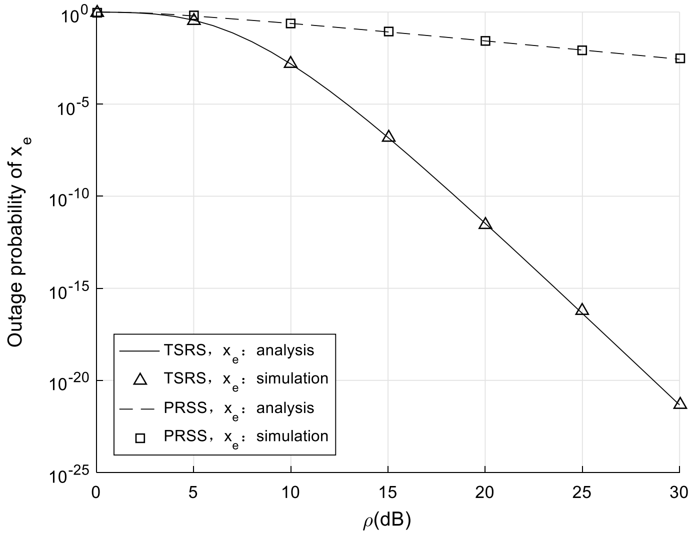


Fig. 2 Outage probability x_e versus of ρ

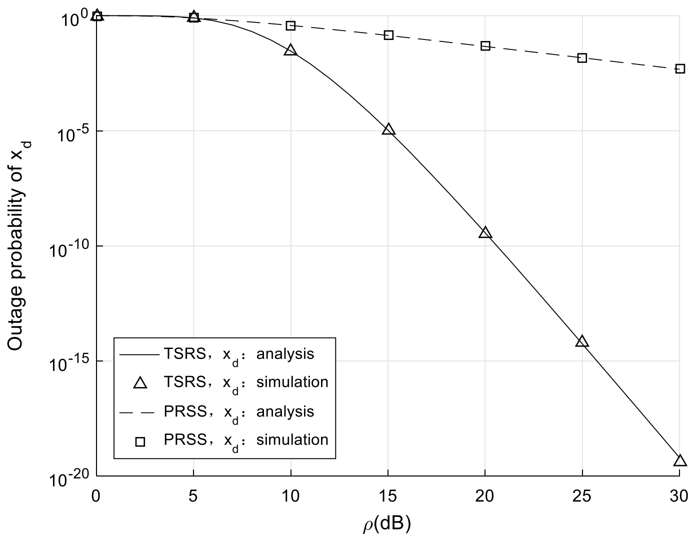


Fig. 3 Outage probability x_d versus of ρ

the relays reaches a certain value. Under the TSRS strategy, as the number of relays is increasing, the OP declines linearly. Noted that the superiority of TSRS scheme is apparent and the outage probability can be effectively reduced with the number of relays increasing. From a practical point of view, it is important to consider

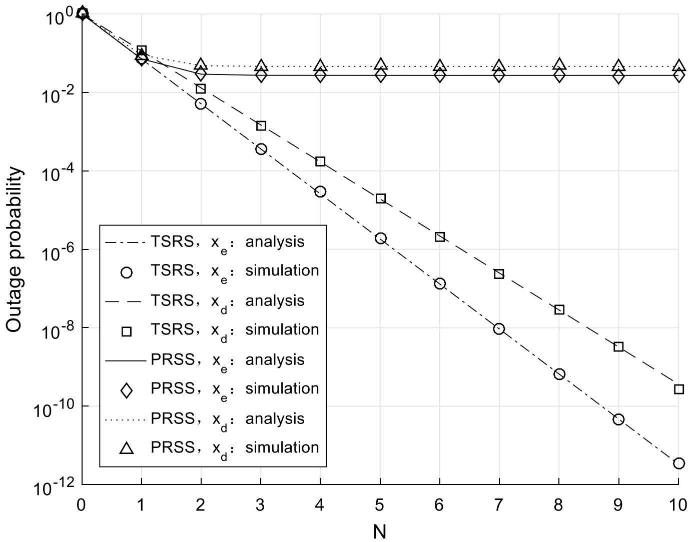


Fig. 4 Outage probability x_e and x_d versus of N

multiple relays scenarios. Furthermore, the TSRS scheme is especially significant for improving the outage performance of EU with poor channel quality.

5 Conclusion

In this paper, D2D communication is applied in the cooperative relaying NOMA network. In the future, the DC-NOMA can be exploited in the nearly local communication of the wireless communication network. Based on the DC-NOMA system, we have proposed a TSRS multiple relays selection scheme. The outage probabilities have been derived and the derivation results are fully consistent with simulation results. It was also shown that, as compared to PRSS scheme, the proposed TSRS scheme can effectively improve the outage performance of the DC-NOMA system. Noted that the increase in the number of relays greatly reduced the signal outage probability, so it can meet the application of large-scale relay scenarios in massive connections in the future.

References

1. Chettri, L., Bera, R.: A comprehensive survey on internet of things (IoT) toward 5G wireless systems. IEEE Internet Things J. **7**(1), 16–32 (2020)
2. Islam, S.M.R., Avazov, N., Dobre, O.A., Kwak, K.: Power-domain non-orthogonal multiple

access (NOMA) in 5G systems: potentials and challenges. IEEE Commun. Surv. Tutor. **19**(2), 721–742 (2017)
3. Li, X., Zhao, M., Liu, Y., Li, L., Nallanathan, A.: Secrecy analysis of ambient backscatter NOMA systems under I/Q imbalance. IEEE Trans. Veh. Technol. **69**(10), 12286–12290 (2020)
4. Yue, X., Liu, Y., Kang, S., Nallanathan, A., Ding, Z.: Exploiting full/half-duplex user relaying in NOMA systems. IEEE Trans. Commun. **66**(2), 560–575 (2018)
5. Ji, Y., Duan, W., Wen, M., Padidar, P., Li, J., Cheng, N., Ho, P.: Spectral efficiency enhanced cooperative device-to-device systems with NOMA. IEEE Trans. Intell. Transport. Syst. **22**(7), 4040–4050 (2021)
6. Lv, L., Chen, J., Ni, Q., Ding, Z., Jiang, H.: Cognitive non-orthogonal multiple access with cooperative relaying: a new wireless frontier for 5G spectrum sharing. IEEE Commun. Mag. **56**(4), 188–195 (2018)
7. Lin, Z., Liu, J., Ming, X., Gang, W., Liang, Y., Li, S.: Performance analysis and optimization in downlink NOMA systems with cooperative full-duplex relaying. IEEE J. Sel. Areas Commun. **35**(10), 2398–2412 (2017)
8. Shen, X.: Device-to-device communication in 5G cellular networks. IEEE Netw. **29**(2), 2–3 (2015)
9. Lee, J., Lee, J.H.: Performance analysis and resource allocation for cooperative D2D communication in cellular networks with multiple D2D pairs. IEEE Commun. Lett. **23**(5), 909–912 (2019)
10. Zhang, Z., Zheng, M., Ming, X., Ding, Z., Fan, P.: Full-duplex device-to-device-aided cooperative nonorthogonal multiple access. IEEE Trans. Veh. Technol. **66**(5), 4467–4471 (2017)
11. Kim, J., Lee, I., Lee, J.: Capacity scaling for D2D aided cooperative relaying systems using NOMA. IEEE Wirel. Commun. Lett. **7**(1), 42–45 (2018)
12. Huang, R., Wan, D., Ji, F., Hua, Q., Chen, F.: Performance analysis of NOMA-based cooperative networks with relay selection. China Commun. **17**(11), 111–119 (2020)
13. Qiao, Y., He, Y., Zhang, L., Yang, J., Zhou, L.: Performance analysis of multiple primary users CR-NOMA networks under partial relay selection. In: Proceedings of the 3rd International Conference on Wireless Communications and Applications (ICWCA), pp. 323–329. Hainan, China (2019)