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A Novel Spectrum Sharing Scheme Assisted by Secondary NOMA Relay

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***Abstract*—In this letter, a two-slot secondary non-orthogonal multiple access (NOMA) relay is used to assist spectrum sharing, where the primary transceivers with long distance communicate through the relay. First, the information for the primary receiver (PR) and secondary receivers (SRs) is transmitted via the NOMA relay. Then, the information for PR is re-transmitted to it through a selected SR to improve its quality of service using maximal-ratio combining, while the next data for PR is sent from the primary transmitter (PT) to the NOMA relay simultaneously. The power allocation solution is derived for the NOMA relay. Simulation results have shown the effectiveness of the proposed scheme.**

***Index Terms*—Maximal-ratio combining, non-orthogonal multiple access, power allocation, relay, spectrum sharing.**

I. INTRODUCTION

Non-orthogonal multiple access (NOMA) is a key technology of the fifth generation (5G) mobile networks [1], in which the transmitters superimpose the signals and send them to the corresponding receivers. At each receiver, the desired signal can be retrieved by successive interference cancellation (SIC), where the signals from poorer channels are eliminated and the signals from better channels are treated as noise.

Recently, NOMA has attracted a lot of interest from both academia and industry, due to its superiority in improving throughput, reducing latency and achieving massive connectivity [2]–[6]. In [2], Ding *et al.* investigated the performance of NOMA, when the users are randomly distributed. The power allocation problem was studied by Wang *et al.* in [3], for weighted sum rate maximization in NOMA systems. In [4], Zhang *et al.* presented a full-duplex device-to-device aided cooperative NOMA scheme, in which the outage probability of NOMA users is improved. A novel NOMA scheme, i.e., pattern division multiple access, was proposed in [5] by Chen *et al.*, which can significantly improve the spectrum efficiency. In [6], Zhang *et al.* maximized the energy efficiency of NOMA systems through optimal power allocation.

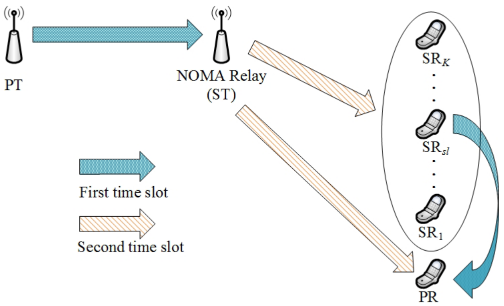

Fig. 1. Demonstration of the secondary NOMA relay assisted spectrum sharing scheme.

Due to its promising performance in spectrum efficiency, NOMA can also be adopted to achieve spectrum sharing in cognitive radio networks [7]. Especially, in [8], Lv *et al.* proposed a NOMA-based cooperative transmission scheme, in which a secondary transmitter (ST) is utilized as a NOMA relay to send signals to both primary receiver (PR) and secondary receivers (SRs). Although the scheme is effective, it is not suitable when the PR is far away from the primary transmitter (PT). Also, the total transmit power of this system can be further improved. Inspired by this work, in this paper, we propose a novel secondary NOMA relay assisted spectrum sharing scheme, in which the information for the PR and SRs is first transmitted via the relay to the relevant destinations. Then, the information for PR is re-transmitted to it through a selected SR to improve its quality of service (QoS) using the maximal-ratio combining (MRC), while the next frame for PR is delivered from the PT to the NOMA relay at the same time. The proposed scheme can not only save the total transmit power of the system, but is also suitable when the PR is far away from the PT.

II. SYSTEM MODEL

Consider a cooperative spectrum sharing network as shown in Fig. 1, where there exist a PT, a PR, a ST and several SRs. Denote the signals required by the PR and the SR_i as x_0 and x_i with unit power, $i \in \mathcal{K} \triangleq \{1, 2, ..., K\}$, respectively. Each node works in a half-duplex mode with a single antenna, and all the channels follow block Rayleigh fading. Denote the channel coefficients from ST to SR_i, from PT to ST, from ST

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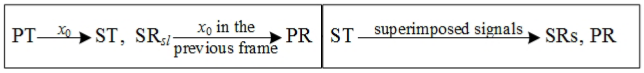

Fig. 2. Time-slot diagram of one frame for the proposed scheme.

to PR, from SR_i to PR and from SR_{sl} to PR, as $h_{s,i}$, $h_{p,s}$, $h_{s,0}$, $h_{i,0}$ and $h_{sl,0}$, respectively, where SR_{sl} is the selected node from SRs to re-transmit x_0 to PR. Assume that the distance between ST and PR is much longer than that between ST and SRs, and thus, the channel gains of PR and SRs are ordered as $|h_{s,0}| \leq |h_{s,1}| \leq ... \leq |h_{s,K}|$. Also, denote P_p, P_s and P_{sl} as the transmit power of PT, ST and SR_{sl}, respectively, and the background noise is modelled as a complex Gaussian random variable with mean zero and variance σ^2. In this letter, we assume that the distance between the PT and PR is long, such that they don't have a direct link[1]. To connect the PT and PR, we utilize a secondary NOMA relay, i.e., the ST, to assist the spectrum sharing between the primary user (PU) and secondary users (SUs).

III. NOMA RELAY ASSISTED SPECTRUM SHARING

In this section, we propose a secondary NOMA relay assisted spectrum sharing scheme as shown in Fig. 2, in which we divide the signal transmission process into two time slots described as follows.

A. *First Time Slot*

In the first time slot, we can choose a receiver SR_{sl} to re-transmit the decoded signal in the previous frame to the PR. To allow a good channel gain for the PR, the SR_{sl} can be chosen as

$$i^* = \arg\max_{i \in \mathcal{K}} |h_{i,0}|^2. \tag{1}$$

The selected SR_{sl} will re-transmit the decoded x_0 of the previous frame to PR. At the same time, x_0 of the current frame is transmitted from the PT to ST. At the ST, the re-transmitted x_0 of the last frame from SR_{sl} can be perfectly eliminated, due to the fact that it has already been decoded successfully and cached locally. Thus, the achievable rate at ST can be expressed as

$$R_{ps} = \log_2\left(1 + P_p |h_{p,s}|^2/\sigma^2\right). \tag{2}$$

To successfully decode x_0 at the ST, the rate should satisfy

$$R_{ps} \geq r_0, \tag{3}$$

where r_0 is the required rate for QoS. Thus, the minimum transmit power of PT can be derived as

$$P_p \geq \sigma^2(2^{r_0} - 1)/|h_{p,s}|^2. \tag{4}$$

ST should not be set very far from PT, to guarantee the successful transmission of x_0 to it.

B. *Second Time Slot*

During the second time slot, conditioned on the successful decoding of x_0 at the ST following (4), the PR can be deemed as a common mobile end together with SRs, and the superimposed signals for both PR and SRs can be transmitted by the ST as

$$x_{ST} = \sum\nolimits_{i=0}^{K} \sqrt{p_i} x_i, \tag{5}$$

where p_0 and p_i are the power allocated to the PR and the ith SR, respectively, $i \in \mathcal{K}$. Since $|h_{s,0}| \leq ... \leq |h_{s,K}|$, we can set $p_0 \geq p_1 \geq ... \geq p_K \geq 0$ with $\Sigma_{i=0}^{K} p_i = P_s$. Let $\alpha_i = |h_{s,i}|^2/\sigma^2$. We have $0 \leq \alpha_0 \leq \alpha_1 \leq ... \leq \alpha_K$. Assume that each SU can adopt SIC to decode the signal of weaker users directly. Thus, the achievable rate of SR_i can be obtained as

$$\begin{aligned} R_i &= \log_2\left(1 + \frac{|h_{s,i}|^2 p_i}{|h_{s,i}|^2 \sum_{j=i+1}^{K} p_j + \sigma^2}\right) \\ &= \log_2\left(1 + \frac{\alpha_i p_i}{\alpha_i \sum_{j=i+1}^{K} p_j + 1}\right). \end{aligned} \tag{6}$$

To decode x_i successfully at SR_i, the following condition should be satisfied as

$$R_i \geq r_i, i \in \mathcal{K}, \tag{7}$$

where r_i is the rate threshold of x_i for the ith SU.

It is assumed that, if SR_1 with the poorest channel among all the SRs can decode x_0, the remaining SRs can also decode x_0. Thus, the achievable rate of SR_1 to successfully decode x_0 is given by

$$R_{x_0 \to 1} = \log_2\left(1 + \frac{\alpha_1 p_0}{\alpha_1 \sum_{j=1}^{K} p_j + 1}\right). \tag{8}$$

According to (8), we can obtain the condition that all the SRs are able to decode x_0 successfully as

$$R_{x_0 \to 1} \geq r_0. \tag{9}$$

In traditional cognitive radio networks, the performance of SUs should be optimized with the requirement of PU guaranteed [9], and thus, PU can maximize its own benefit earned from the spectrum access of SUs. Thus, to maximize the sum rate of SRs, the optimization problem can be formulated as

$$\begin{aligned} \max_{p_0, p_1, p_2, \ldots, p_K} \; & \sum\nolimits_{i=1}^{K} R_i \\ s.t. \quad & R_i \geq r_i, i \in \mathcal{K}, \\ & R_{x_0 \to 1} \geq r_0, \\ & p_0 \geq p_1 \geq ... \geq p_K \geq 0, \\ & \sum\nolimits_{i=0}^{K} p_i = P_s, \end{aligned} \tag{10}$$

which will be solved in Section IV.

The information for PR can be decoded using the received signal in the NOMA process and the re-transmission by SR_{sl} described in Section III-A. In our proposed scheme, MRC is adopted to guarantee the reliable transmission of PU, and we can get the achievable rate at PR as

$$R_p = \log_2\left(1 + \frac{P_{sl}|h_{sl,0}|^2}{\sigma^2} + \frac{\alpha_0 p_0}{\alpha_0 \sum_{i=1}^{K} p_i + 1}\right), \tag{11}$$

in which the interference from PT is not considered at the PR

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[1] When PT and PR are not so far from each other, the scheme in [8] can be utilized instead, in which the link between the PT and PR cannot be neglected.

in the first time slot, due to the long distance between them. To decode x_0 at PR successfully, we need

$$R_p \geq r_0. \tag{12}$$

Thus, the minimum transmit power of P_{sl} can be derived as

$$P_{sl} \geq \frac{\sigma^2}{|h_{sl,0}|^2}\left(2^{r_0} - 1 - \frac{\alpha_0 p_0}{\alpha_0 \sum_{i=1}^{K} p_i + 1}\right). \tag{13}$$

For a given P_s, the remaining transmit power of the system should satisfy

$$P_{sum} = P_p + P_{sl}. \tag{14}$$

Remark: In our proposed scheme, the information for the PR and SRs is first transmitted via the NOMA relay ST to destinations. Then, the PR's information is re-transmitted to it through a selected SR to improve its QoS using MRC, with the information for PR of the next time slot delivered from the PT to the NOMA relay simultaneously. Due to the use of the two time slots, the total transmit power of the system can be significantly reduced while still satisfying the requirements of the PR and SRs, especially when the PR is far away from PT. In addition, the whole system is controlled by ST with necessary control signals.

IV. SOLUTION TO POWER ALLOCATION PROBLEM

In the proposed scheme, the transmit power at the ST for the PR and SRs should be properly allocated according to (10) in Section III. To solve the problem, we first define $q_i = \sum_{j=i}^{K} p_j$ for $i = 0, ..., K$. Thus, $p_i = q_i - q_{i+1}$ for $i = 0, ..., K-1$, and $q_K = p_K$. Then, (6) can be rewritten as

$$R_i = \log_2(1 + \alpha_i q_i) - \log_2(1 + \alpha_i q_{i+1}), \tag{15}$$

for $i = 1, ..., K-1$ and $R_K = \log_2(1 + \alpha_K q_K)$. Also, (7) can be expressed as

$$q_{i+1} \leq \eta_i q_i - \beta_i, \tag{16}$$

for $i = 1, ..., K-1$, and $q_K \geq \theta_K$ for $i = K$, where $\eta_i = 2^{-r_i}$, $\beta_i = (1 - \eta_i)/\alpha_i$, and $\theta_i = (2^{r_i} - 1)/\alpha_i$. In addition, (9) can be expressed as

$$q_1 \leq \eta_0 q_0 + (\eta_0 - 1)/\alpha_1. \tag{17}$$

The condition $p_0 \geq p_1 \geq ... \geq p_K \geq 0$ with $\sum_{i=0}^{K} p_i = P_s$ can also be changed into $q_0 - q_1 \geq q_1 - q_2 \geq ... \geq q_K \geq 0$ with $q_0 = P_s$. Define $f_1(q_1) = \log_2(1 + \alpha_1 q_1)$ and $f_i(q_i) = \log_2(1 + \alpha_i q_i) - \log_2(1 + \alpha_{i-1} q_i)$ for $i = 2, ..., K$, and the sum rate of SRs can be denoted as

$$\sum\nolimits_{i=1}^{K} R_i = \sum\nolimits_{i=1}^{K} f_i(q_i). \tag{18}$$

Thus, (10) can be rewritten as

$$\begin{aligned} \max_{q_1, q_2, ..., q_K} \; & \sum\nolimits_{i=1}^{K} f_i(q_i) \\ s.t. \quad & q_{i+1} \leq \eta_i q_i - \beta_i, i = 1, ..., K-1, \\ & q_1 \leq \eta_0 q_0 + (\eta_0 - 1)/\alpha_1, \\ & q_0 - q_1 \geq q_1 - q_2 \geq ... \geq q_K \geq \theta_K, \\ & q_0 = P_s. \end{aligned} \tag{19}$$

Lemma 1: The problem in (19) is convex.

Proof: The first-order derivative of $f_i(q_i)$ for $i \in \mathcal{K}$ can be presented as

$$f_i'(q_i) = \begin{cases} \dfrac{1}{\ln 2\left(\frac{1}{\alpha_1} + q_1\right)}, & i = 1, \\ \dfrac{\frac{1}{\alpha_{i-1}} - \frac{1}{\alpha_i}}{\ln 2\left(\frac{1}{\alpha_i} + q_i\right)\left(\frac{1}{\alpha_{i-1}} + q_i\right)}, & i = 2, ..., K. \end{cases} \tag{20}$$

Since $\alpha_i \geq \alpha_{i-1} \geq 0$ and $q_i \geq 0$, we can obtain that $f_i'(q_i) \geq 0$ for $i \in \mathcal{K}$. The second-order derivative of $f_i(q_i)$ for $i \in \mathcal{K}$ can be derived as

$$f_i''(q_i) = \begin{cases} -\dfrac{1}{\ln 2(\frac{1}{\alpha_1} + q_1)^2}, & i = 1, \\ \dfrac{(\frac{1}{\alpha_i} + q_i)^2 - (\frac{1}{\alpha_{i-1}} + q_i)^2}{\ln 2(\frac{1}{\alpha_{i-1}} + q_i)^2(\frac{1}{\alpha_i} + q_i)^2}, & i = 2, ..., K. \end{cases} \tag{21}$$

Apparently, $f_i''(q_i) \leq 0$, and all the constraints in (19) are linear. Thus, we conclude that the problem (19) is convex. ■

Although (19) is convex, its closed-form optimal solution is difficult to find. If we first relax the constraint $q_0 - q_1 \geq q_1 - q_2 \geq ... \geq q_K \geq \theta_K$, a closed-form solution can be derived as given in Proposition 1.

Proposition 1: If the constraint $q_0 - q_1 \geq q_1 - q_2 \geq ... \geq q_K \geq \theta_K$ can be relaxed, solution to (19) can be expressed as

$$\hat{q}_i = \begin{cases} P_s, & i = 0, \\ \eta_0 \hat{q}_0 + (\eta_0 - 1)/\alpha_1, & i = 1, \\ \eta_{i-1}\hat{q}_{i-1} - \beta_{i-1}, & i = 2, ..., K, \end{cases} \tag{22}$$

and thus, the solution to (10) can be derived as

$$\hat{p}_i = \begin{cases} (1 - \eta_0)\hat{q}_0 - (\eta_0 - 1)/\alpha_1, & i = 0, \\ (1 - \eta_i)\hat{q}_i + \beta_i, & i = 1, ..., K-1, \\ \hat{q}_K, & i = K. \end{cases} \tag{23}$$

Proof: We can show that each $f_i(q_i)$ is nondecreasing because their first-order derivative $f_i'(q_i) \geq 0$ for $i \in \mathcal{K}$, which has been proved in Lemma 1. To maximize $\sum_{i=1}^{K} f_i(q_i)$, the constraints $q_{i+1} \leq \eta_i q_i - \beta_i$ for $i = 1, ..., K-1$ and $q_1 \leq \eta_0 q_0 + \frac{\eta_0 - 1}{\alpha_1}$ should take the equality. Thus, using $q_0 = P_s$, we can derive the closed-form expressions of q_i as in (22), $i = 0, 1, \ldots, K$. In addition, p_i can be obtained from $p_i = q_i - q_{i+1}$ for $i = 1, ..., K-1$ and $q_K = p_K$ for $i = K$, as in (23). Therefore, Proposition 1 is proved. ■

When we add some constraints to the solutions in Proposition 1, the constraint $q_0 - q_1 \geq q_1 - q_2 \geq ... \geq q_K \geq \theta_K$ can also be satisfied, which is expressed in Corollary 1.

Corollary 1: The closed-form solutions to (19) and (10) can be expressed as Proposition 1, when the following additional constraints are satisfied.

$$r_i \geq \begin{cases} \log_2(2 - 2^{-r_{i+1}}), & i = 0, ..., K-2, \\ 1, & i = K-1, \end{cases} \tag{24}$$

$$p_k \geq (2^{r_K} - 1)/\alpha_K. \tag{25}$$

Proof: According to (22) and (23), we have $\hat{p}_i - \hat{p}_{i+1} = (1 - \eta_i)\hat{q}_i + \beta_i - (1 - \eta_{i+1})\hat{q}_{i+1} - \beta_{i+1} = (1 -$

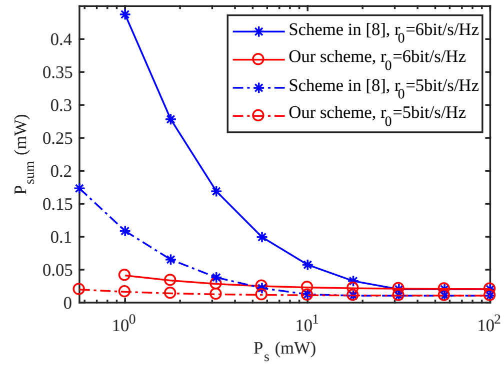

Fig. 3. Comparison of P_{sum} with different values of P_s for the proposed scheme and the scheme in [8].

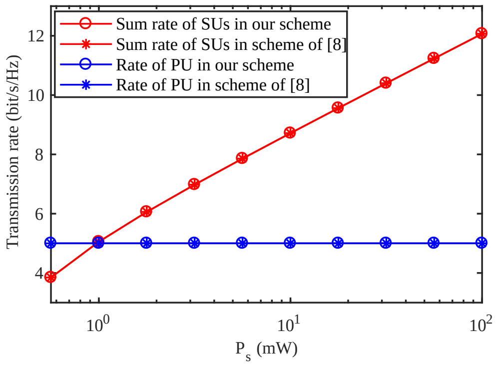

Fig. 4. Comparison of transmission rate with different values of P_s for the proposed scheme and the scheme in [8]. r_0=5 bit/s/Hz.

$(2-2^{-r_{i+1}})2^{-r_i})\hat{q}_i + (2-2^{-r_{i+1}})(1-2^{-r_i})/\alpha_i - (1-2^{-r_{i+1}})/\alpha_{i+1}$, $i=1,2,...,K-2$. If $1-(2-2^{-r_{i+1}})2^{-r_i} \geq 0$, according to $\alpha_{i+1} \geq \alpha_i \geq 0$, we can obtain $(2-2^{-r_{i+1}})(1-2^{-r_i})/\alpha_i - (1-2^{-r_{i+1}})/\alpha_{i+1} \geq (2-2^{-r_{i+1}})(1-2^{-r_i})/\alpha_i - (1-2^{-r_{i+1}})/\alpha_i = (1-(2-2^{-r_{i+1}})2^{-r_i})/\alpha_i \geq 0$, and $\hat{p}_i - \hat{p}_{i+1} \geq 0$. From $1-(2-2^{-r_{i+1}})2^{-r_i} \geq 0$, we can get $r_i \geq \log_2(2-2^{-r_{i+1}})$, $i=1,...,K-2$. Similarly, we can get $r_0 \geq \log_2(2-2^{-r_1})$ from $\hat{p}_0 - \hat{p}_1 \geq 0$, and $r_{K-1} \geq 1$ from $\hat{p}_{K-1} - \hat{p}_K \geq 0$. Thus, (24) is achieved. From $q_K \geq \theta_K$, we can get $p_k \geq \frac{(2^{r_K}-1)\sigma^2}{|h_{s,K}|^2} = \frac{(2^{r_K}-1)}{\alpha_K}$, which is (25). Thus, Corollary 1 is proved. ■

From Corollary 1, we can know that when $r_i \geq 1$ for $i = 0,...,K-1$, (24) will hold, and (25) is a necessary condition for the proposed NOMA spectrum sharing scheme.

V. SIMULATION RESULTS

In the simulation, three SRs are considered, i.e., $K=3$. The path loss exponent is set to 2, and the noise power is $\sigma^2 = 10^{-7}$ mW. The rate thresholds of SUs are all set to 1 bit/s/Hz, i.e., $r_1 = r_2 = r_3 = 1$ bit/s/Hz. We assume that the PT is located at the coordinates (0, 0), the ST is located at (50m, -10m), and the PR is located at (300m, 10m), which is far away from PT. The horizontal coordinates of the SRs are randomly generated between 150m and 200m, and the longitudinal coordinates are between -10m and 10m.

In Fig. 3, P_{sum} for the proposed scheme and the scheme in [8] are compared, with r_0 equal to 5 bit/s/Hz and 6 bit/s/Hz, respectively. To guarantee fair comparison, the transmit power allocated by ST to each PR and SR in the second slot of these two schemes is both optimized according to (10). From the results, we can see that the total transmit power of our proposed scheme is much lower than the scheme in [8]. In addition, when P_s increases, the remaining transmit power P_{sum} will decrease, due to the fact that less power is needed by SR$_{sl}$ to re-transmit x_0 for PR. The first points on the two curves when r_0=6 bit/s/Hz are missed, because the rate requirements of SUs can be met only when P_s is high enough.

The transmission rate of PU and the sum rate of SUs are compared for different values of P_s in Fig. 4, when the proposed scheme and the scheme in [8] are used. From the results, it shows that the sum rate of SUs increases when P_s increases, with the QoS of PU guaranteed. In addition, we can see that the proposed scheme and the scheme in [8] have the same rates with the same P_s. This is because r_0 is set to 5 bit/s/Hz in both schemes, and the same power of P_s is allocated at ST according to the same optimization function (10), for fair comparison between these two schemes. Thus, we can conclude that our proposed scheme can achieve the same rate performance but with much lower transmit power.

VI. CONCLUSIONS AND FUTURE WORK

In this letter, we have proposed a novel secondary NOMA relay assisted spectrum sharing scheme using two time slots. First, the primary information was transmitted from PT to ST. At the same time, a selected SR re-transmitted the primary information of the last frame to PR. Then, the ST transmitted the information for PR and SRs via NOMA in the second time slot. Thus, the QoS of PU can be guaranteed through MRC, with the sum rate of SUs maximized. Simulation results were presented to show the effectiveness of the proposed scheme. Future work will be focused on the fairness among SRs.

REFERENCES

[1] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan, and V. Bhargava, “A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends,” *IEEE J. Sel. Areas Commun.*, vol. 35, no. 10, pp. 2181–2195, Oct. 2017.

[2] 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.

[3] J. Wang, Q. Peng, Y. Huang, H.-M. Wang, and X. You, “Convexity of weighted sum rate maximization in NOMA systems,” *IEEE Signal Process. Lett.*, vol. 24, no. 9, pp. 1323–1327, Sep. 2017.

[4] Z. Zhang, Z. Ma, M. Xiao, Z. Ding, and P. Fan, “Full-duplex device-to-device-aided cooperative nonorthogonal multiple access,” *IEEE Trans. Veh. Technol.*, vol. 66, no. 5, pp. 4467–4471, May 2017.

[5] S. Chen, B. Ren, Q. Gao, S. Kang, S. Sun, and K. Niu, “Pattern division multiple access-A novel nonorthogonal multiple access for fifth-generation radio networks,” *IEEE Trans. Veh. Technol.*, vol. 66, no. 4, pp. 3185–3196, Apr. 2017.

[6] Y. Zhang, H.-M. Wang, T.-X. Zheng, and Q. Yang, “Energy-efficient transmission design in non-orthogonal multiple access,” *IEEE Trans. Veh. Technol.*, vol. 66, no. 3, pp. 2852–2857, Mar. 2017.

[7] Y. Liu, Z. Ding, M. Elkashlan, and J. Yuan, “Nonorthogonal multiple access in large-scale underlay cognitive radio networks,” *IEEE Trans. Veh. Technol.*, vol. 65, no. 12, pp. 10152–10157, Dec. 2016.

[8] L. Lv, Q. Ni, Z. Ding, and J. Chen, “Application of non-orthogonal multiple access in cooperative spectrum-sharing networks over nakagami-m fading channels,” *IEEE Trans. Veh. Technol.*, vol. 66, no. 6, pp. 5510–5515, Jun. 2017.

[9] S. Agarwal and S. De, “eDSA: Energy-efficient dynamic spectrum access protocols for cognitive radio networks,” *IEEE Trans. Mobile Comput.*, vol. 15, no. 12, pp. 3057–3071, Dec. 2016.