Performance Analysis of Relay Based NOMA Cooperative Transmission under Cognitive Radio Network

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Abstract: This paper proposes a hybrid spectrum accessing mechanism by using NOMA-based cooperative transmission and beam-forming technology. In this mechanism, the secondary user employs spectrum-sensing technology to detect the existence of the primary user. If the primary user does not exist, the secondary source user directly transmits data to the destination user. If the primary user exists, the secondary source user finds the optimal relay according to certain selection principle before transmitting data to the destination user through the chosen relay node. For the signal receiving stage, the secondary user takes use of beam-forming technology to receive the signal from both the secondary source and the secondary relay node. Meanwhile the interference from the primary user is cancelled out in the stage. Furthermore, the outage probability for secondary user in the proposed mechanism is theoretically derived. Finally, the simulation results show that compared with the traditional mechanism, the proposed system model can not only guarantee the continuity of secondary transmission, but also significantly reduce the outage probability of secondary transmission.

Keywords: Relay selection, outage probability, NOMA, QoS, signal-to-interference-plus-noise rate (SINR), beam-forming.

1 Introduction

Recent years, non-orthogonal multiple access (NOMA) has been paid intensive attention. NOMA and cognitive radio are two of the key technologies in 5G technology and play an important role in solving the shortage of spectrum resources. The research of both NOMA and cognitive technology is named cognitive NOMA technology [Yu, He and Li (2017); Ding, Fan, Poor et al. (2016)], which can realize optimized spectrum sharing and increase the spectrum efficiency.

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As known, cognitive radio can effectively utilize the wireless spectrum, where secondary user uses spectrum sensing technology to detect the idle spectrum of the primary user, and shares the authorized frequency band with the primary user through spectrum access technology [Wang and Liu (2011); Zheng, Song, Wong et al. (2013)]. Up to now, the applications of new technologies in wireless cognitive networks have been paid intensive attention by researchers. For example, millimeter wave band communication, beam-forming, MIMO, heterogeneous wireless network and cooperative transmission technologies have been introduced into wireless cognitive network to construct a new framework to further improve spectrum efficiency. In particular, the existing researches on the technologies combing NOMA and CR [Lv, Ni, Chen et al. (2017); Ding, Fan and Poor. (2016); Liu, Ding, Elkashlan et al. (2016); Liang, Ding, Li et al. (2017); Lv, Chen, Ni et al. (2017)] have shown that CR-NOMA technology is likely to meet the requirements of 5G wireless networks, such as high throughput, big connection, and low latency. For example, in Yang et al. [Yang, Ding, Fan et al. (2016)], the author proposed a minimum mean square error channel estimation model, where the outage performance of NOMA and OMA is compared for the case with channel errors. The results show that the average sum rate of NOMA system is always better than that of OMA. In Tsiropoulos et al. [Tsiropoulos, Dobre, Ahmed et al. (2016)], the authors proposed an enhanced relay cooperative transmission model. In the transmission process, users with good channel conditions are considered as relays to assist users with poor channel conditions to transmit data in the next slot. Compared with the traditional NOMA scheme, this model can effectively improve the transmission performance of users with poor channel conditions and enable them to obtain higher channel capacity. To enhance the performance of NOMA communications when secondary users are too far away from each other or the channel quality is unsatisfactory, relays can also be introduced to the system. Several relay selection schemes are discussed in Yu et al. [Yu, Liu, Zhang et al. (2019)]. In Men et al. [Men, Ge and Zhang (2017)], a scheme using idle devices is proposed in the cooperative NOMA transmission, which combines NOMA with relay network to improve the network's spectrum efficiency and analyze the network's outage performance. In addition, the integration of full duplex technology with cognitive NOMA can further improve spectral efficiency. When transmitter and receiver have full duplex capability, they can simultaneously finish downlink and uplink transmission using the same spectrum resource.

Based on the above researches, in wireless cognitive networks, secondary transmission is always constrained by the primary user. Thus, whether the primary user transmits signal or not will significantly affect the performance of the secondary network. For the Interweave mode, the secondary network only transmits signal when the primary user is idle. Once the primary user begins to transmit, the secondary user should immediately release the spectrum, which directly interrupts the secondary transmission. For the Underlay mode, the secondary network can take use of the spectrum of the primary user so as not to degrade the Quality of Service (QoS) of primary transmission. The main concern lies in how to ensure the continuity of secondary transmission and reduce the probability of secondary outage without affecting the communication quality of primary user, which is also the focus of paper.

This paper proposes a hybrid spectrum access mechanism based on NOMA and beam-forming. In the improved mechanism, the secondary user first uses spectrum-sensing technology to detect the existence of the primary user. If the primary user does not exist, the secondary source user transmits data directly to the destination user (U_1, U_2) according to its own power limit. If the primary user exists, the secondary source user should consider both the power constraint imposed by the primary user on the secondary network and the equipment limitation of the secondary user itself. To further the transmission scope, relay solution is always employed to transfer data between the transmitter and the final receivers. Meantime, in the improved mechanism, the beam-forming technology is adopted at the secondary targeted user to receive useful signals from both the secondary source user and the secondary optimal relay while the interference from the primary user is cancelled out. Finally, the formula of outage probability for the secondary user in the improved mechanism is derived. In addition, the secondary outage probability of the improved mechanism is simulated and compared with the traditional mechanism. Simulation results show that the adaptive mechanism can not only guarantee the continuity of secondary transmission, but also reduce the outage probability of secondary transmission.

2 System model

In the NOMA-based cooperative transmission model, a primary user randomly accesses an authorized frequency band and sends data to the public destination user P_0. Meantime, secondary source user S send their own data to two destination users (U_1, U_2) by sharing the frequency band of the primary user. In addition, it is assumed that U_1 and U_2 can be equipped with multiple antennas to implement beam-forming technology.

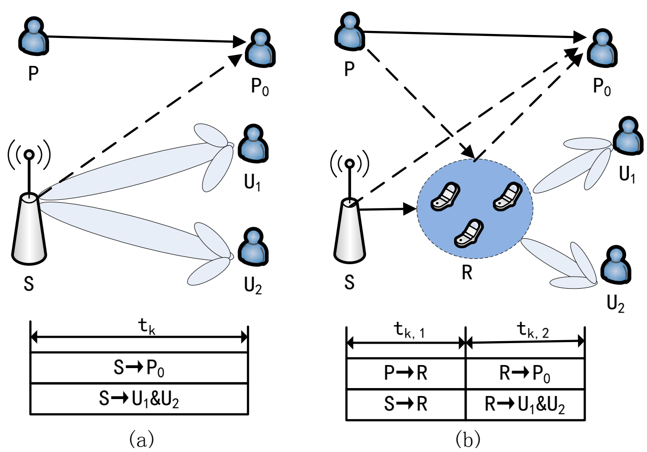

Figure 1: Relay cooperative NOMA network

As shown in Fig. 1, in underlay cognitive radio networks, h_1, h_2 stands for the link channel coefficient from S to U_1 and U_2, respectively. The channel coefficient between the user i and the user j is denoted by h_{ij}. In addition, the total transmission power at secondary transmitter is limited by E_S. Similarly, define the transmission power of primary user as E_P, and α represents the path loss exponent.

2.1 Protocol description

There are two transmission mechanisms:

As shown in Fig. 1(a), when the primary user does not exist, S directly transmits data to U_1 and U_2.

Similarly, in Fig. 1(b), if the primary user exists, each transmission slot t_k is divided into two sub-slots with equal length $t_{k,1}$ and $t_{k,2}$. S transmits data to U_1 and U_2 through the cooperation of relays to expand the transmission range under the constraint of ensuring the QoS of the primary user. The time slot structure is analyzed as follows.

When the primary user does not exist, S directly transmits data to the destination node. The received signal of U_1 and U_2 can be written as:

$$y_{U_1,H_0} = h_1(\sqrt{a_1 E_S}x_1 + \sqrt{a_2 E_S}x_2)+n_{SU_1}, \tag{1}$$

$$y_{U_2,H_0} = h_2(\sqrt{a_1 E_S}x_1 + \sqrt{a_2 E_S}x_2)+n_{SU_2}. \tag{2}$$

where both n_{SU_1}, and n_{SU_2} are the additive white Gaussian noise of user U_1 and U_2 with variance σ_0^2. $a_i(i=1,2)$ is the power allocation coefficient with the condition of $a_1 < a_2$ and $a_1+a_2=1$.

When the primary user exists, in the first time slot $t_{k,1}$, S transmits data to P_0 and relay R_i. Obviously, the primary and secondary transmissions will interfere with each other. So the received signal at R_i and P_0 are derived as:

$$y_{R,H_1} = h_{SR_i}(\sqrt{a_1 E_S}x_1 + \sqrt{a_2 E_S}x_2)+\sqrt{E_P}h_{PR_i}x_P + n_{SR_i}, \tag{3}$$

$$y_{P,H_1} = \sqrt{E_P}h_{PP_0}x_P + h_{SP_0}(\sqrt{a_1 E_S}x_1 + \sqrt{a_2 E_S}x_2) + n_{SP_0}. \tag{4}$$

where n_{SR_i}, n_{SP_0} are the additive white Gaussian noise of user R_i and P_0 with variance σ_0^2.

Then, all secondary relays decode the transmitted signal from S. Those secondary relays which can successfully decode the signal constitute a decoding set Ξ.

In the second time slot $t_{k,2}$, there are two cases about decoding set Ξ.

Case 1: If Ξ is empty (i.e., no relay can successfully decode the signal from S), a direct transmission link is used to retransmit its data to U_1 and U_2. Meantime, at U_1 and U_2, beam-forming technology is used to receive signal from S in order to cancel interference from the primary user. Then, the received signal at U_1 and U_2 can be expressed as:

$$y_{U_1,H_1,\Theta} = h_1(\sqrt{a_1 E_S}x_1 + \sqrt{a_2 E_S}x_2) + n_{SU_1}, \tag{5}$$

$$y_{U_2,H_1,\Theta} = h_2(\sqrt{a_1 E_S}x_1 + \sqrt{a_2 E_S}x_2) + n_{SU_2}. \tag{6}$$

Case 2: If Ξ is not empty, the relay in Ξ that leads to the maximum Signal-to-noise rate (SNR) of U_1, U_2 would be selected as the best one to assist signal transmission. Here, the best relay is denoted as R_B. U_1 and U_2 receive signals from R_B through beam-forming technology. Specifically, U_1 and U_2 adjust the beam of its antenna pattern aligning with R_B, while zero aligns with the primary user. Therefore, interference from the primary user can be restrained to be almost zero. Then, the received signal for U_1 and U_2 are given by:

$$y_{U_1,H_1} = h_{RU_1}(\sqrt{a_1 E_S}x_1 + \sqrt{a_2 E_S}x_2) + n_{R_iU_1}, \tag{7}$$

$$y_{U_2,H_1} = h_{RU_2}(\sqrt{a_1 E_S}x_1 + \sqrt{a_2 E_S}x_2) + n_{R_iU_2}. \tag{8}$$

where $n_{R_iU_1}$, $n_{R_iU_2}$ are the additive white Gaussian noise of link R_iU_1 and R_iU_2 with variance σ_0^2.

2.2 Calculation of SINR

Case 1: If the primary user does not exist, S directly transmits data to U_1 and U_2, then the SINR at the receivers are derived as

$$\gamma_{1\to 2,\mathrm{H}_0} = \frac{a_2\gamma_S |h_1|^2}{a_1\gamma_S |h_1|^2 + 1}, \tag{9}$$

$$\gamma_{1,H_0} = a_1\gamma_S |h_1|^2, \tag{10}$$

$$\gamma_{2,\mathrm{H}_0} = \frac{a_2\gamma_S |h_2|^2}{a_1\gamma_S |h_2|^2 + 1}. \tag{11}$$

where $\gamma_P = \frac{E_P}{\sigma_0^2}$ and $\gamma_S = \frac{E_S}{\sigma_0^2}$.

Case 2: If the primary user exists, in $t_{k,1}$, the SINR at R_i are written as:

$$\gamma_{SR1} = \frac{a_1\gamma_S |h_{SR_i}|^2}{\gamma_P |h_{PR_i}|^2 + 1}, \tag{12}$$

$$\gamma_{\mathrm{SR2}} = \frac{a_2\gamma_S |h_{SR_i}|^2}{a_1\gamma_S |h_{SR_i}|^2 + \gamma_P |h_{PR_i}|^2 + 1}. \tag{13}$$

Then, all secondary relays decode the transmitted signal. In $t_{k,2}$, there are two cases as follows:

If Ξ is empty, S will control the transmission power and retransmit signal through the direct link. The SINR of U_1 and U_2 are given by:

$$\gamma_{1\to 2,\mathrm{H}_1} = \frac{a_2\gamma_S |h_1|^2}{a_1\gamma_S |h_1|^2 + 1}, \tag{14}$$

$$\gamma_{1,H_1} = a_1\gamma_S |h_1|^2, \tag{15}$$

$$\gamma_{2,\mathrm{H}_1} = \frac{a_2\gamma_S |h_2|^2}{a_1\gamma_S |h_2|^2 + 1}. \tag{16}$$

If Ξ is not empty, in the second time slot, the SINR of U_1 and U_2 are written as:

$$\gamma_{1\to 2,RU_1} = \frac{a_2\gamma_{U_i} \left|h_{RU_1}\right|^2}{a_1\gamma_{U_i} \left|h_{RU_1}\right|^2 + 1}, \tag{17}$$

$$\gamma_{1,RU_1} = a_1\gamma_{U_i} \left|h_{RU_1}\right|^2, \tag{18}$$

$$\gamma_{2,RU_2} = \frac{a_2\gamma_{U_i} \left|h_{RU_2}\right|^2}{a_1\gamma_{U_i} \left|h_{RU_2}\right|^2 + 1}. \tag{19}$$

where $\gamma_{U_i} = E_R/\sigma_0^2$.

3 Power control scheme

To simplify the analysis, the target rate is set as $R_1 = R_2 = R_R = R^*$, the maximum power threshold of secondary system is set as $E_S = E_P$. Therefore, the channel capacity threshold in the direct transmission link is written as $\gamma_{H_0} = 2^{R^*} - 1$. When the primary user exists, the secondary user transmits data to the destination through relay cooperation, and the channel capacity threshold in the cooperative transmission link is $\gamma_{H_1} = 2^{2R^*} - 1$.

From Eq. (4), when there is P, the outage probability of the primary link $P \to P_0$ is derived as

$$\begin{aligned} Pout_{PP_0} &= \Pr\left\{ \frac{\gamma_P \left|h_{PP_0}\right|^2}{\gamma_S \left|h_{SP_0}\right|^2 + 1} < \gamma_{H_0} \right\} \\ &= 1 - \frac{\gamma_P \sigma_{PP_0}^2}{\gamma_{H_0}\gamma_S\sigma_{SP_0}^2 + \gamma_P\sigma_{PP_0}^2} \mathrm{e}^{-\frac{\gamma_{H_0}}{\gamma_P\sigma_{PP_0}^2}}, \end{aligned} \tag{20}$$

In order to ensure the QoS of the primary user, $Pout_{PP_0}$ should satisfies the condition $Pout_{PP_0} \le \varepsilon$, where ε is the outage probability threshold. Thus, the maximum transmission power of S is restrained by:

$$E_{S,P} = E_P \sigma^2_{PP_0} \max\left(\frac{1}{1-\varepsilon} \mathrm{e}^{-\frac{\gamma_{H_0}}{\gamma_P \sigma^2_{PP_0}}} - 1, 0\right) / \left(\gamma_{H_0} \sigma^2_{SP_0}\right). \tag{21}$$

Similarly, when the decoding set is not empty, the maximum transmission power of R is calculated as:

$$E_{R,P} = E_P \sigma^2_{PP_0} \max\left(\frac{1}{1-\varepsilon} \mathrm{e}^{-\frac{\gamma_{H1}}{\gamma_P \sigma^2_{PP_0}}} - 1, 0\right) / \left(\gamma_{H_1} \sigma^2_{RP_0}\right). \tag{22}$$

In the Underlay mode, in order to meet the QoS of the primary transmission network, considering the characteristics of low transmission power and small transmission range of the secondary transmission network, the proposed mechanism adopts the non-adaptive power allocation strategy for secondary user, which is more suitable for the power allocation requirements in real situations. In the traditional mechanism, the transmission power of the secondary network only needs to satisfy the QoS of the primary transmission network. In the proposed improved mechanism, not only the outage probability of the primary user should be ensured not to exceed certain threshold, but also the transmission power of the secondary user needs to be controlled. Meanwhile, the secondary user in the improved mechanism cannot exceed the maximum transmission power threshold defined by the system.

In the proposed mechanism, the maximum transmission power of S and R_i are given by:

$$E_S = \min(E_{S,P}, E_{S,Max}), \tag{23}$$

$$E_R = \min(E_{R,P}, E_{R,Max}). \tag{24}$$

4 Outage performance analysis

It is assumed that the time interval of primary transmission obeys exponential distribution with parameter μ_1, and the duration of primary transmission obeys exponential distribution with parameter μ_2. The probability that the primary user does not exist is defined as:

$$\Pr\{\mathrm{H}_0\} = \mu, \tag{25}$$

$$\Pr\{\mathrm{H}_1\} = 1 - \mu. \tag{26}$$

where H_0 and H_1 denote the cases that the primary user does not exist and does exist respectively.

When the primary uses do not exist, from Eqs. (8), (9) and (10), the outage probability of the secondary user U_1 is deduced as:

$$
\begin{aligned}
Pout_{\mathrm{H}_0}^{u_1} &= 1-\Pr\{\gamma_{1\to 2,\mathrm{H}_0} > \gamma_{H_0}, \gamma_{1,\mathrm{H}_0} > \gamma_{H_0}\} \\
&= 1-\Pr\{\frac{a_2\gamma_S|h_1|^2}{a_1\gamma_S|h_1|^2+1} > \gamma_{H_0}, a_1\gamma_S|h_1|^2 > \gamma_{H_0}\} \\
&= 1-\Pr\{|h_1|^2 > \frac{\gamma_{H_0}}{\gamma_S(a_2-a_1\gamma_{H_0})}, |h_1|^2 > \frac{\gamma_{H_0}}{a_1\gamma_S}\} \\
&= \begin{cases} 1-e^{-\frac{\gamma_{H_0}}{\gamma_S(a_2-a_1\gamma_{H_0})\Omega_{SU_1}}}, & \gamma_{H_0} < \frac{a_2}{a_1} < \gamma_{H_0}+1 \\ 1-e^{-\frac{\gamma_{H_0}}{\gamma_S a_1\Omega_{SU_1}}}, & \frac{a_2}{a_1} > \gamma_{H_0}+1 \end{cases}.
\end{aligned} \tag{27}
$$

The outage probability of the secondary use U_2 is expressed as:

$$
\begin{aligned}
Pout_{\mathrm{H}_0}^{u_2} &= 1-\Pr\{\gamma_{2,\mathrm{H}_0} > \gamma_{H_0}\} \\
&= 1-\Pr\{\frac{a_2\gamma_S|h_2|^2}{a_1\gamma_S|h_2|^2+1} > \gamma_{H_0}\} \\
&= 1-e^{-\frac{\gamma_{H_0}}{\gamma_S(a_2-a_1\gamma_{H_0})\Omega_{SU_2}}}, \quad \frac{a_2}{a_1} > \gamma_{H_0}.
\end{aligned} \tag{28}
$$

Assuming the target rate $R_1 = R_2 = R_R = R^*$, when the primary user does not exist, secondary user directly transmit data to the receiver. The target rate can be written as $R^* = \log_2(1+\gamma_{H_0})$, the threshold of the direct link is $\gamma_{H_0} = 2^{R^*}-1$.

Similarly, when the primary user exists, the secondary user transmits data to the receiver through the cooperation of optimal relay. Therefore, the target rate of the receiver is given as $R^* = \frac{1}{2}\log_2(1+\gamma_{H_1})$, and the channel transmission threshold is written as $\gamma_{H_1} = 2^{2R^*}-1$.

When the primary user exists, during the cooperative transmission, R_i decodes the signal x_1 and x_2. Thus, the probability that R_i can successfully decode the secondary transmitted signal x_S during $t_{k,1}$ is given by

$$PD_{R_i} = \Pr\{\gamma_{\text{SR1}} > \gamma_{H_1}, \gamma_{\text{SR2}} > \gamma_{H_1}\}$$
$$=\Pr\{\left|h_{SR_i}\right|^2 > \frac{\gamma_{H_1}(\gamma_P\left|r_{PR_i}\right|^2+1)}{\gamma_S(a_2-a_1\gamma_{H_1})}, \left|r_{SR_i}\right|^2 > \frac{\gamma_{H_1}(\gamma_P\left|h_{PR_i}\right|^2+1)}{\gamma_S a_1}\} \tag{29}$$
$$= \begin{cases} \dfrac{(a_2-a_1\gamma_{H_1})\gamma_S\Omega_{SR_i}}{\gamma_{H_1}\gamma_P\Omega_{PR}+(a_2-a_1\gamma_{H_1})\gamma_S\Omega_{SR_i}} e^{-\frac{\gamma_{H_1}}{(a_2-a_1\gamma_R)\gamma_S\Omega_{SR_i}}}, \gamma_{H_1} < \dfrac{a_2}{a_1} < \gamma_{H_1}+1 \\ \dfrac{a_1\gamma_S\Omega_{SR_i}}{\gamma_{H_1}\gamma_P\Omega_{PR_i}+a_1\gamma_S\Omega_{SR_i}} e^{-\frac{\gamma_{H_1}}{a_1\gamma_S\Omega_{SR_i}}}, \quad \dfrac{a_2}{a_1} > \gamma_{H_1}+1 \end{cases}.$$

When the primary use exists, the probability of $\Xi = \Theta$ and $\Xi = \Omega_l$ can be obtained by:

$$PC_\Theta = \Pr\{\Xi = \Theta\} = \prod_{i=1}^{N}\left(1 - PD_{R_i}\right), \tag{30}$$

$$PC_{\Omega_n} = \Pr\{\Xi = \Omega_n\} = \prod_{i\in\Omega_n} PD_{R_i} \prod_{j\in\bar{\Omega}_n}\left(1 - PD_{R_i}\right). \tag{31}$$

Case 1: When the primary user exist, and Ξ is empty, the outage probability of the secondary user U_1 is written as:

$$Pout_{\text{H}_1,\Theta}^{u_1} = 1 - \Pr\{\gamma_{1\to 2,\text{H}_1} > \gamma_{H_1}, \gamma_{1,\text{H}_1} > \gamma_{H_1}\}$$
$$=1 - \Pr\{\frac{a_2\gamma_{S,Max}\left|h_1\right|^2}{a_1\gamma_{S,Max}\left|h_1\right|^2+1} > \gamma_{H_1}, a_1\gamma_{S,Max}\left|h_1\right|^2 > \gamma_{H_1}\}$$
$$=1 - \Pr\{\left|h_1\right|^2 > \frac{\gamma_{H_1}}{\gamma_{S,Max}(a_2-a_1\gamma_{H_1})}, \left|h_1\right|^2 > \frac{\gamma_{H_1}}{a_1\gamma_{S,Max}}\} \tag{32}$$
$$= \begin{cases} 1 - e^{-\frac{\gamma_{H_1}}{\gamma_{S,Max}(a_2-a_1\gamma_{H_1})\sigma_{SU_1}^2}}, \ \gamma_{H_1} < \dfrac{a_2}{a_1} < \gamma_{H_1}+1 \\ 1 - e^{-\frac{\gamma_{H_1}}{\gamma_{S,Max}a_1\sigma_{SU_1}^2}}, \quad \dfrac{a_2}{a_1} > \gamma_{H_1}+1 \end{cases}.$$

The outage probability of the secondary user U_2 is expressed as:

$$Pout_{\text{H}_2,\Theta}^{u_2} = 1 - \Pr\{\gamma_{2,\text{H}_1} > \gamma_{H_1}\}$$
$$=1 - \Pr\{\frac{a_2\gamma_S\left|h_2\right|^2}{a_1\gamma_S\left|h_2\right|^2+1} > \gamma_{H_1}\} \tag{33}$$
$$=1 - e^{-\frac{\gamma_{H_1}}{\gamma_S(a_2-a_1\gamma_{H_1})\Omega_{SU_2}}}, \quad \frac{a_2}{a_1} > \gamma_{H_1}.$$

Case 2: When the decoding set Ξ is not empty, S will choose the optimal relay R_B from the decoding set Ξ to assist the transmission of x_S. Here, the optimal relay is the one in the decoding set that enables the secondary target user achieving the best outage performance. Therefore, the principle is given by:

$$R_B = \arg\max_{j\in\Omega_l}\left(\min(\gamma_{1\to 2,R_jU_1},\gamma_{1,R_jU_1},\gamma_{2,R_jU_2})\right). \tag{34}$$

From Eqs. (11) to (15), when any one relay R_i in the decoding set cooperatively transmits signal, the outage probability of the secondary use U_1 and U_2 are calculated as:

$$\begin{aligned} Pout_{R_i}^{u_1} &= 1-\Pr\{\frac{a_2\gamma_S\left|h_{R_iU_1}\right|^2}{a_1\gamma_S\left|h_{R_iU_1}\right|^2+1} > \gamma_{H_1}, a_1\rho\left|h_{R_iU_1}\right|^2 > \gamma_{H_1}\} \\ &= \begin{cases} e^{-\frac{\gamma_{H_1}}{\gamma_S(a_2-a_1\gamma_{H_1})\Omega_{R_iU_1}}}, & \gamma_{H_1} < \dfrac{a_2}{a_1} < \gamma_{H_1}+1 \\ e^{-\frac{\gamma_{H_1}}{\gamma_S(a_2-a_1\gamma_{H_1})\Omega_{R_iU_1}}}, & \dfrac{a_2}{a_1} > \gamma_{H_1}+1 \end{cases}. \end{aligned} \tag{35}$$

$$\begin{aligned} Pout_{R_i}^{u_2} &= 1-\Pr\{\gamma_{2,\mathrm{SU}_2} > \gamma_{H_1}\} \\ &= 1-e^{-\frac{\gamma_{H_1}}{\gamma_S(a_2-a_1\gamma_{H_1})\Omega_{R_iU_2}}}, \quad \frac{a_2}{a_1} > \gamma_{H_1}. \end{aligned} \tag{36}$$

Through the selection process of candidate relays, the optimal relay transmission is achieved. Thus, the outage probability of the secondary users is given by:

$$Pout_{\Omega_n}^{u_1} = \prod_{U_j\in\Omega_n} Pout_{R_i}^{u_1}, \tag{37}$$

$$Pout_{\Omega_n}^{u_2} = \prod_{U_j\in\Omega_n} Pout_{R_i}^{u_2}. \tag{38}$$

So, when the primary use exists, the outage probability of secondary transmissions is expressed as:

$$Pout_{\mathrm{H}_1}^{u_1} = Pout_{\mathrm{H}_1,\Theta}^{u_1}\Pr\{\Xi=\Theta\} + \sum_{n=1}^{2^N-1} Pout_{\Omega_n}^{u_1}\Pr\{\Xi=\Omega_n\}, \tag{39}$$

$$Pout_{\mathrm{H}_1}^{u_2} = Pout_{\mathrm{H}_1,\Theta}^{u_2}\Pr\{\Xi=\Theta\} + \sum_{n=1}^{2^N-1} Pout_{\Omega_n}^{u_2}\Pr\{\Xi=\Omega_n\}. \tag{40}$$

Further, the secondary outage probability can be derived as:

$$Pout_{U_1} = Pout_{\mathrm{H}_0}^{u_1}\Pr(H_0) + Pout_{\mathrm{H}_1}^{u_1}\Pr(H_1), \tag{41}$$

$$Pout_{U_2} = Pout_{\mathrm{H}_0}^{u_2}\Pr(H_0) + Pout_{\mathrm{H}_1}^{u_2}\Pr(H_1). \tag{42}$$

Actually, when there is no secondary user in CRN ($N=0$), $\Pr\{\Xi=\Theta\}=1$ and $\Pr\{\Xi=\Omega_l\}=0$. Meantime, if the secondary receiver does not employ beam-forming technology, the user S will control the transmission power and retransmitted signal through the direct link. The SINR of U_1 and U_2 are given by:

$$\gamma_{1\to 2,\mathrm{P}} = \frac{a_2\gamma_S|h_1|^2}{a_1\gamma_S|h_1|^2+\gamma_P|h_{PU_1}|^2+1} \tag{43}$$

$$\gamma_{1,\mathrm{P}} = \frac{a_1\gamma_S|h_1|^2}{\gamma_P|h_{PU_1}|^2+1} \tag{44}$$

$$\gamma_{2,\mathrm{P}} = \frac{a_2\gamma_S|h_2|^2}{a_1\gamma_S|h_2|^2+\gamma_P|h_{PU_2}|^2+1} \tag{45}$$

Therefore, the traditional secondary outage probability can be derived as:

$$\begin{aligned} Pout_{\Theta}^{u_1} &= 1-\Pr\{\gamma_{1\to 2,\mathrm{P}}>\gamma_{H_0},\gamma_{1,\mathrm{P}}>\gamma_{H_0}\} \\ &= 1-\Pr\{\frac{a_2\gamma_S|h_1|^2}{a_1\gamma_S|h_1|^2+\gamma_P|h_{PU_1}|^2+1}>\gamma_{H_0},\frac{a_1\gamma_S|h_1|^2}{\gamma_P|h_{PU_1}|^2+1}>\gamma_{H_0}\} \\ &= \begin{cases} 1-\dfrac{(a_2-a_1\gamma_{H_0})\gamma_S\Omega_{SU_1}}{\gamma_{H_0}\gamma_P\Omega_{PU_1}+(a_2-a_1\gamma_{H_0})\gamma_S\Omega_{SU_1}}e^{-\frac{\gamma_{H_0}}{(a_2-a_1\gamma_{H_0})\gamma_S\Omega_{SU_1}}}, & \gamma_{H_0}<\dfrac{a_2}{a_1}<\gamma_{H_0}+1 \\ 1-\dfrac{a_1\gamma_S\Omega_{SU_1}}{\gamma_{H_0}\gamma_P\Omega_{PU_1}+a_1\gamma_S\Omega_{SU_1}}e^{-\frac{\gamma_{H_0}}{a_1\gamma_S\Omega_{SU_1}}}, & \dfrac{a_2}{a_1}>\gamma_{H_0}+1 \end{cases} \end{aligned} \tag{46}$$

$$\begin{aligned} Pout_{\Theta}^{u_2} &= 1-\Pr\{\gamma_{2,\mathrm{P}}>\gamma_{H_0}\} \\ &= 1-\Pr\{\frac{a_2\gamma_S|h_2|^2}{a_1\gamma_S|h_2|^2+\gamma_P|h_{PU_2}|^2+1}>\gamma_{H_0}\} \\ &= 1-\frac{(a_2-a_1\gamma_{H_0})\gamma_S\Omega_{SU_2}}{\gamma_{H_0}\gamma_P\Omega_{PU_2}+(a_2-a_1\gamma_{H_0})\gamma_S\Omega_{SU_2}}e^{-\frac{\gamma_{H_0}}{\gamma_S(a_2-a_1\gamma_{H_0})\Omega_{SU_2}}},\ \frac{a_2}{a_1}>\gamma_{H_0}. \end{aligned} \tag{47}$$

Using $\Pr\{\Xi=\Theta\}=1$ and $\Pr\{\Xi=\Omega_l\}=0$ in Eqs. (41) and (42), the outage probability of the conventional principle can be concluded.

5 Simulation and analysis

In this paper, the target rate of the user data in the system is set as $R^*=0.85$ bits/s/Hz **,** the number of relay is 4, i.e., $N=4$, the power allocation factor is set to be $a_1=0.3$, $a_2=0.7$, and the channel variance is defined as $\sigma_{PR_0}^2=\sigma_{SU_1}^2=\sigma_{SR_B}^2==\sigma_{R_BU_1}^2=1$ and $\sigma_{SR_0}^2=\sigma_{PU_1}^2=\sigma_{PU_2}^2=\sigma_{PR_B}^2=0.2$.

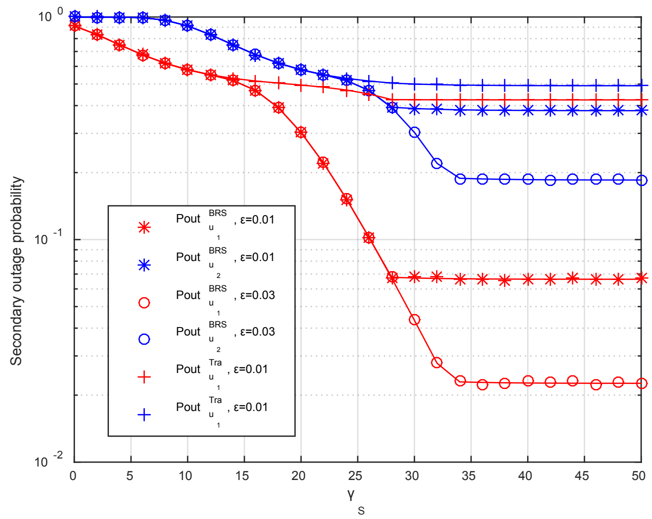

Figure 2: Secondary outage probability *vs.* transmit SNR γ_S with different threshold ε

Fig. 2 shows the transmit SNR $\gamma_S = E_S / \sigma_n^2$ on the secondary outage probability for different ε which is the predefined threshold to ensure the QoS of the primary user, where $\gamma_P = 30\,dB$. It is observed that the secondary outage probability of the proposed mechanism is much lower than the traditional NOMA mechanism. To ensure the QoS of primary user, Secondary users need to set their transmission power according to the primary network and secondary network. From Eq. (23), the transmission power can neither exceed the maximum power E_S allowed by the secondary system nor exceed the transmission power $E_{S,Max}$ limited by the QoS of primary user. When the value $\gamma_S = E_S / \sigma_n^2$ is small, the power limitation of the secondary system is the main factor that affects the secondary outage probability. And the secondary outage probability will decrease with the increase of $\gamma_S = E_S / \sigma_n^2$. However, when the value $\gamma_S = E_S / \sigma_n^2$ increases, the transmission power of the secondary user in the improved mechanism is limited by the QoS of primary user. Therefore, the increase of $\gamma_S = E_S / \sigma_n^2$ will not change the transmission power of the secondary system, and the secondary outage probability remains the same. It is obvious that there exists a critical value $\gamma_{S,Thr}$, which is the SNR of the system. If $\gamma_S < \gamma_{S,Thr}$, the transmission power will be determined by the secondary maximum transmission power. Otherwise, it will be determined by the constraint of the primary user. In addition, as shown in Fig. 2, the critical value is related to the predefined threshold ε of the primary outage probability. As ε increases, the outage probability of the secondary user decreases, which is due to the fact that more transmission power is allowed for secondary users in this case.

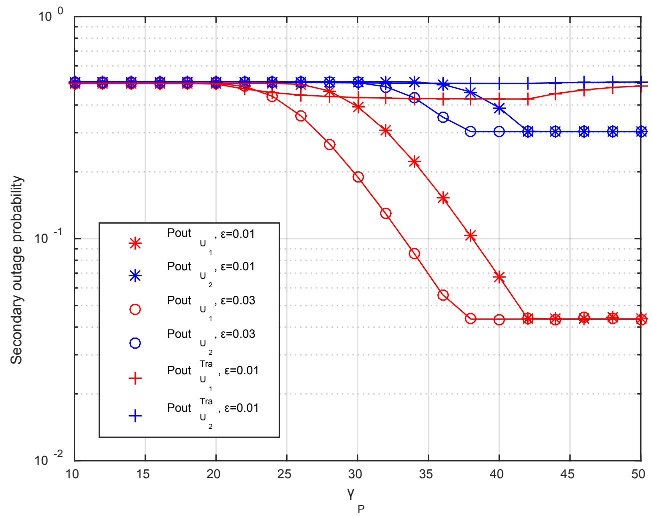

Figure 3: Secondary outage probability *vs.* transmit SNR $\gamma_P = E_P / \sigma_n^2$ with different threshold ε

Fig. 3 shows the comparison of the secondary outage probability of the traditional mechanism and the proposed mechanism under different values ε. As shown in this figure, when γ_P is small, to protect the primary transmission, the secondary transmission is only executed when the primary user does not exist, and the transmission is forbidden when the primary user exists, so the secondary outage probability equals to 1/2. Then, with an appropriately increased γ_P, the secondary outage probability will decrease, which is due to the increase of transmission power $E_{S,Max}$ limited by the QoS of primary user. However, when the value γ_P is large, in the traditional mechanism, the transmission power of secondary user is only limited by the primary system, and the interference of primary user will seriously affect the transmission performance of secondary user. The secondary outage probability will increase with the increase of γ_P. In the proposed mechanism, if γ_P is large, the transmission power is determined by the maximum transmission power of secondary transmitter. So the increase of γ_P will not change the transmission power of the secondary system, and the secondary outage probability remains the same. As shown in Fig. 3, the critical value is related to the predefined threshold ε of the primary outage probability. As ε increases, the outage probability of the secondary user decreases, which is due to the fact that more transmission power is required for secondary users in this case.

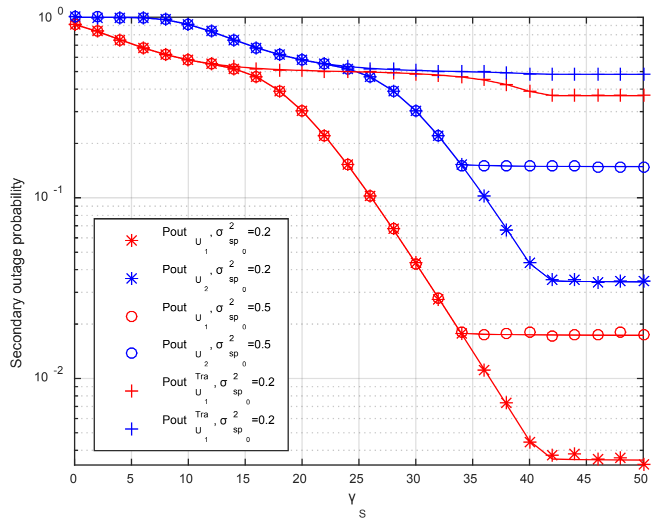

Figure 4: Secondary outage probability *vs.* transmit SNR $\gamma_S = E_S / \sigma_n^2$ with different channel variance

Fig. 4 shows the transmission SNR $\gamma_S = E_S / \sigma_n^2$ on the secondary outage probability for different $\sigma_{SP_0}^2$. Similar to Fig. 2, the improved mechanism achieves a much lower secondary outage probability than the traditional mechanism. It can be seen that with the increase of $\sigma_{SP_0}^2$, the secondary outage probability will increase, and the secondary network causes much more interference to the primary user. As the transmission power E_S of the secondary user decreases, the secondary outage probability would increase accordingly.

Fig. 5 shows the simulation results of the secondary outage probability of both the traditional mechanism and the improved mechanism under the different transmit SNR of the primary user. Similar to Fig. 3, the secondary outage probability of the improved mechanism is lower than that of the traditional mechanism. From Fig. 5, with an increasing $\sigma_{SP_0}^2$, the secondary outage probability will increase. With the increase of $\sigma_{SP_0}^2$, the secondary network causes much more interference to the primary user. So the secondary transmission power E_S should be constrained, which deteriorates the secondary outage performance.

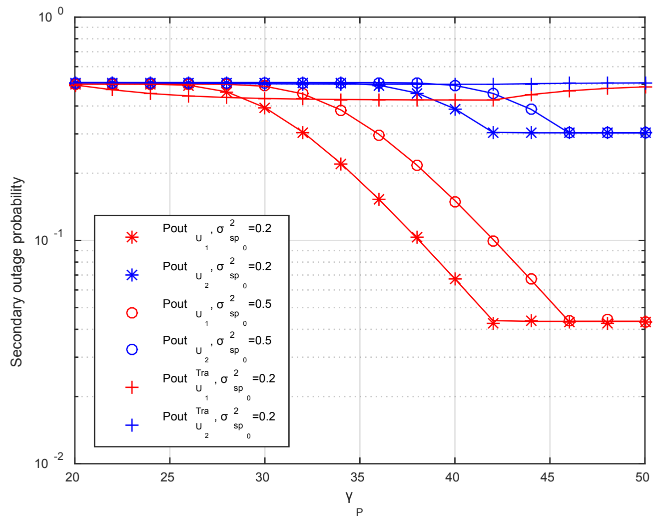

Figure 5: Secondary outage probability *vs.* transmit SNR $\gamma_P = E_P / \sigma_n^2$ with different channel variance

6 Conclusions

In order to solve the problem of secondary transmission outage caused by frequent occupancy of authorized spectrum by primary user, this paper proposed an improved spectrum access mechanism based on beam-forming, optimal relay selection, power control and NOMA. The main purpose of this mechanism is to ensure the continuity of secondary transmission and reduce the secondary outage probability without affecting the normal operation of the primary user. Furthermore, the outage probability of the improved mechanism is derived and compared with the traditional mechanism. Finally, simulation results confirmed that compared with the traditional mechanism, the proposed mechanism significantly improves the performance of secondary transmission.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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