DUAL RELAY SELECTION STRATEGY FOR COOPERATIVE NOMA NETWORKS

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In this paper, we consider cooperative non-orthogonal multiple access (NOMA) relaying networks, where one base station (BS) communicates with two users with the aid of multiple relays. In order to further reduce the outage probability and enhance the transmission performance of the users, we consider using two relays for data transmission instead of one. Max-min dual relay selection strategy and triple dual relay selection strategy are proposed for the cooperative NOMA network with decode-and-forward (DF) relaying protocols. The results of analysis and simulation show that the max-min dual relay selection strategy and the triple dual relay selection strategy have better outage performance than the existing single relay selection strategies developed for cooperative NOMA.

Key Words : *NOMA, relay selection, dual relay, outage probability*

1. INTRODUCTION

NOMA has recently received enormous interest as a promising candidate to significantly improve the spectral efficiency of the fifth generation (5G) wireless networks1). The basic idea of NOMA is to use superposition coding for signal transmission, which is divided into the power domain and the code domain. Code domain based NOMA exploits a unique spreading code for each user, whereas power domain based NOMA allocates different power to each user2). Therefore, different users can have the same time domain resources and frequency domain resources. Users utilize successive interference cancellation (SIC) to eliminate inter-user interference. The user with poor channel conditions decodes first, then removes its message from the signal, and the next user continues to decode3).

The idea of user cooperation for NOMA was firstly proposed in [4]. The authors analyzed the diversity order and outage probability of the cooperative NOMA scheme, and proved that cooperative NOMA can achieve the maximum diversity gain for all the users. In [5], a dual-hop relay selection strategy has been proposed, which analyzes the outage probability and the average rate of the NOMA network with DF and amplify-and-forward (AF). The simulation results show that the outage performance of DF relay is better than that of AF relay in cooperative NOMA networks. In [6], the performance of cooperative NOMA partial relay selection (PRS) based system under outdated channel state information (CSI) was investigated. The simulation results show that the relay position, relay selection strategy and channel correlation coefficient can significantly affect the performance of the cooperative NOMA networks. A two-stage DF dual relay selection for two users cooperative NOMA was proposed in [1], where the power of users is divided according to their quality of service (QoS) rather than channel conditions. The simulation results show that the relay selection strategy can further reduce the outage probability, but the priority of high-QoS users are not considered in the relay selection process. A two-stage relay selection strategy was proposed to reduce the outage probability of high-QoS users in [7]. In the first stage, select the relay which can achieve the transmission rate of high-QoS users, and in the second stage, select the relay that can maximize the transmission rate of low-QoS users. The simulation results show that the transmission rate of users with low-QoS is increased while reducing the outage probability. Different from other relay selection strategies that aim to reduce the outage probability, a buffer-aided relay selection strategy with the goal of improving the total throughput of cooperative NOMA networks users was proposed in [8]. All relays can buffer the data and select the working mode that can maximize the system throughput to achieve throughput improvement. In [9], the impact of the number of relay nodes and power allocation on the CR-NOMA networks was studied and verified. The simulation results show that increasing the number of relays can provide better outage performance.

In the cooperative NOMA networks, the BS establishes contact with the users through the relay. In order to ensure the continuity of communication, good channel conditions are required from the BS to the relay and from the relay to the users. At present, most relay selection strategies adopt single relay selection. In practical application, it is very difficult to find a single relay with these conditions. In order to solve the problem of single relay selections, dual relay selection is a good scheme.

In this paper, we consider a cooperative NOMA network with one BS communicates with two users via multiple relays. In order to solve the problem of poor outage performance caused by single relay selections, max-min dual relay selection strategy is proposed. To further improve the outage performance and to consider the priority of high-QoS users in the relay selection process, triple dual relay selection strategy is proposed.

The remainder of this paper is organized as follows. Section 2 introduces the system model and the conditions for users to decode their own messages. In Section 3, two existing relay selection strategies are introduced and two new dual relay selection strategies are proposed. Simulation results are presented in Section 4 to demonstrate the outage performance of the proposed strategies. The conclusions are finally presented in Section 5.

2. SYSTEM MODEL

Consider a cooperative NOMA network consisting of a BS and multiple communication nodes with relay capabilities. In a process of transmission, BS is the source node, and other communication nodes can be divided into user nodes, relay nodes and irrelevant nodes that do not participate in this communication. The system model can be simplified by ignoring irrelevant nodes.

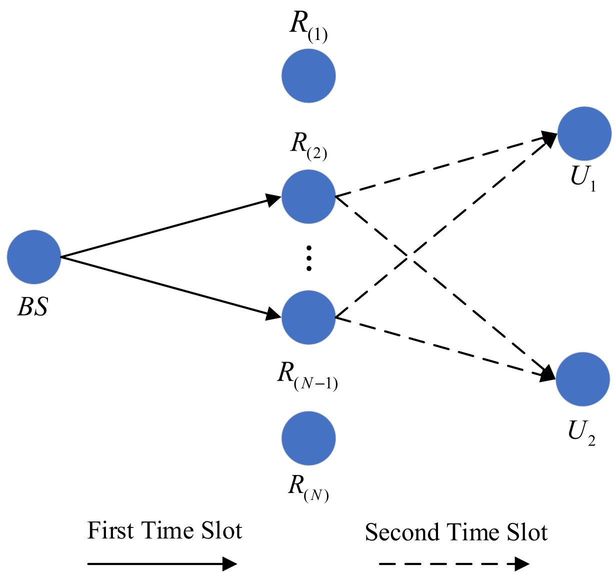

Fig.1 System model of the cooperative NOMA network.

The simplified cooperative NOMA network consisting of a source S, e.g., a BS, N half-duplex relays R, and two users U1 and U2, as depicted in Fig. 1. There is no direct link between the BS and the users, and the channel of each link is modeled as identically and independently distributed Rayleigh fading. Relays use DF instead of AF. In this model, we only consider the downlink, that is the data transmission link from the BS to the users, and use NOMA in the power domain. The power allocation factor is divided according to their QoS requirements, rather than channel conditions. Users with high-QoS will be allocated more power. Assume that user 1 needs a low data rate but quick connection, e.g., network alarm and navigation system, and user 2 is a user who requires a high data rate but does not need a quick connection, e.g., network video player and network downloader. Therefore, the power of user 1 is always bigger than the power of user 2 in this system model.

During the first time slot, the BS will transmit the superimposed signal of all users. The superimposed signal is given by

$$y = \sqrt{P_{BS}}\alpha_1 x_1 + \sqrt{P_{BS}}\alpha_2 x_2 \quad (1)$$

where P_{BS} denotes the power of BS, x_i denotes the signal to user i, and α_i denotes the power allocation coefficient. Assume that $P_{BS} = 1$ at this system mode. Note that $\alpha_1^2 + \alpha_2^2 = 1$ and $\alpha_1 \geq \alpha_2$ since user 1's QoS requirements are given higher priority.

Therefore, the signal received at the relay n ($1 \leqslant n \leqslant N$) can can be written as:

$$y_n = h_n \sqrt{P_{BS}} (\alpha_1 x_1 + \alpha_2 x_2) + w_n \quad (2)$$

where h_n denotes the channel gain between the BS and relay n, and w_n denotes additive Gaussian noise.

Assume that the SIC can be successfully carried out at the system modle. The relay first decodes x_1, and then remove it from their received signal. x_2 can be decoded after that. The conditions for a relay to decode the two messages, x_1 and x_2, are given by[7)]

$$\frac{1}{2}\log_2\left(1+\frac{|h_n|^2 \alpha_1^2}{|h_n|^2 \alpha_2^2 + 1/\rho}\right) \geq R_1 \quad (3)$$

and

$$\frac{1}{2}\log_2\left(1+\rho |h_n|^2 \alpha_2^2\right) \geq R_2 \quad (4)$$

where ρ denotes the transmit signal-to-noise ratio (SNR) and R_i denotes the target data rate for user i.

During the second time slot, users decode their own messages. Divide the description into two cases: single-relay and dual-relay.

(a) Single relay selection

Assume that relay n can successfully decode x_1 and x_2, and the signal received by the user i can be written as follows:

$$y_{n,i} = g_{n,i} \sqrt{P_R} \left(\alpha_1 x_1 + \alpha_2 x_2\right) + w_{n,i} \quad (5)$$

where P_R denotes the power of relay, $g_{n,i}$ denotes the channel gain between relay n and user i, and $w_{n,i}$ denotes additive Gaussian noise. Note that $P_R = 1$, equal to the power of BS.

User 1 directly decodes its message, the condition to decode x_1 is given as follows:

$$\frac{1}{2}\log_2\left(1+\frac{|g_{n,1}|^2 \alpha_1^2}{|g_{n,1}|^2 \alpha_2^2 + 1/\rho}\right) \geq R_1 \quad (6)$$

User 2 needs to carry out SIC, and decodes its message after removing user 1's message. The condition to decode x_1 at user 2 can be written as follows:

$$\frac{1}{2}\log_2\left(1+\frac{|g_{n,2}|^2 \alpha_1^2}{|g_{n,2}|^2 \alpha_2^2 + 1/\rho}\right) \geq R_1 \quad (7)$$

The condition to decode x_2 can be expressed as:

$$\frac{1}{2}\log_2\left(1+\rho |g_{n,2}|^2 \alpha_2^2\right) \geq R_2 \quad (8)$$

(b) Dual relay selection

Also assume that relay n can successfully decode x_1 and x_2, and the signal received by the user i can be written as follows:

$$y_{n,i} = \sqrt{P_R}\left(g_{n_1,i} + g_{n_2,i}\right)\left(\alpha_1 x_1 + \alpha_2 x_2\right) + w_{n_1,i} + w_{n_2,i} \quad (9)$$

The condition to decode x_1 at user 1 is given by

$$\frac{1}{2}\log_2\left(1+\frac{\left(|g_{n_1,1}|^2 + |g_{n_2,1}|^2\right)\alpha_1^2}{\left(|g_{n_1,1}|^2 + |g_{n_2,1}|^2\right)\alpha_2^2 + 1/\rho}\right) \geq R_1 \quad (10)$$

User 2 also needs to carry out SIC. The condition to decode x_1 at user 2 is given by

$$\frac{1}{2}\log_2\left(1+\frac{\left(|g_{n_1,2}|^2 + |g_{n_2,2}|^2\right)\alpha_1^2}{\left(|g_{n_1,2}|^2 + |g_{n_2,2}|^2\right)\alpha_2^2 + 1/\rho}\right) \geq R_1 \quad (11)$$

The condition to decode x_2 is given by

$$\frac{1}{2}\log_2\left(1+\rho\left(|g_{n_1,2}|^2 + |g_{n_2,2}|^2\right)\alpha_2^2\right) \geq R_2 \quad (12)$$

The system is considered in an outage state for single relay selection when any one of the conditions in (3), (4), (6), (7) and (8) is not met. For dual relay selection, the conditions are (3), (4), (10), (11) and (12). Since $|g_{n_1,i}|^2 + |g_{n_2,i}|^2$ is always bigger than $|g_{n,i}|^2$, it can be clearly found that the data transmission rate of formulas (10), (11), (12) is higher than formulas (6), (7), (8). It can be inferred from this that the dual relay selection strategy can achieve better performance than the single relay selection strategy.

3. RELAY SELECTION STRATEGY

In this section, two existing relay selection strategies are introduced, max-min relay selection strategy and two-stage relay selection strategy. In order to improve the outage performance, max-min dual relay selection strategy and triple dual relay selection strategy are proposed.

(1) Max-min relay selection strategy

The aim of this strategy is to select the relay with the best overall channel condition for the BS and users from all relays. First select the minimum value from $|h_n|^2$, $|g_{n,1}|^2$ and $|g_{n,2}|^2$. Then select the maximum value from these minimum value of all relays. The relay with the maximum value will be selected for transmission. The relay selection can be obtained as follows[10)]:

$$n^* = \max\left\{\min\left\{|h_n|^2, |g_{n,1}|^2, |g_{n,2}|^2\right\}, 1 \leq n \leq N\right\} \quad (13)$$

(2) Two-stage relay selection strategy

This relay selection strategy was first proposed in [7], which aims to reduce the outage probability of user with high-QoS and serve the other with a rate as large as possible.

In the first stage, the relays which can satisfy the target rate of user with high-QoS are selected. These relays can be obtained by

$$\Phi_r = \left\{ n \left| \frac{1}{2}\log_2\left(1+\frac{|h_n|^2\alpha_1^2}{|h_n|^2\alpha_2^2+1/\rho}\right) \geq R_1 \right. \right.$$

$$\frac{1}{2}\log_2\left(1+\frac{|g_{n,1}|^2\alpha_1^2}{|g_{n,1}|^2\alpha_2^2+1/\rho}\right) \geq R_1,$$

$$\left. \frac{1}{2}\log_2\left(1+\frac{|g_{n,2}|^2\alpha_1^2}{|g_{n,2}|^2\alpha_2^2+1/\rho}\right) \geq R_1 \right\} \tag{14}$$

In the second stage, the relay that can maximize the rate for the other user is selected in Φ_r. The relay which is selected for transmission can be expressed as:

$$n^* = \arg\max_n \left\{ \min\left\{ \frac{1}{2}\log_2\left(1+\rho|h_n|^2\alpha_2^2\right), \right.\right.$$

$$\left.\left. \frac{1}{2}\log_2\left(1+\rho|g_{n,2}|^2\alpha_2^2\right) \right\}, n \in \Phi_r \right\} \tag{15}$$

(3) Max-min dual relay selection strategy

Relay with good channel conditions to BS and users is selected according to the max-min relay selection strategy. In other words, this kind of strategy is suitable for the network where the target rate of two users is similar. It cannot get good results when the target rate of two users differs too much. In order to reduce the outage probability in this situation, we propose the max-min dual relay selection strategy.

First, select the first relay according to the max-min relay selection strategy. The first relay can be obtained as follows:

$$n_1^* = \max\left\{ \min\left\{ |h_n|^2, |g_{n,1}|^2, |g_{n,2}|^2 \right\}, 1 \leq n \leq N \right\} \tag{16}$$

Then select the second relay again among the remaining relays. The second relay can be obtained as follows:

$$n_2^* = \max\left\{ \min\left\{ |h_n|^2, |g_{n,1}|^2, |g_{n,2}|^2 \right\}, 1 \leq n \leq N, n \neq n_1^* \right\} \tag{17}$$

Both relays are used for data transmission.

(4) Triple dual relay selection strategy

To further reduce the outage probability, Triple dual relay selection strategy is proposed in this paper.

First, the relays which can successfully decode the messages for user 1 and user 2 are selected. The subset of the relays can be defined as follows:

$$\Phi_r = \left\{ n : 1 \leq n \leq N, \frac{1}{2}\log_2\left(1+\frac{|h_n|^2\alpha_1^2}{|h_n|^2\alpha_2^2+\frac{1}{\rho}}\right) \geq R_1, \right.$$

$$\left. \frac{1}{2}\log_2\left(1+\rho|h_n|^2\alpha_2^2\right) \geq R_2 \right\} \tag{18}$$

Second, combine two relays in Φ_r as a group and select the relay combinations which can reach the rate of user with high-QoS. The subset of the relay combinations can be defined as follows:

$$\Psi_r = \left\{ (n_1, n_2) \middle| n_1 \in \Phi_r, n_2 \in \Phi_r, n_1 \neq n_2, \right.$$

$$\left. \frac{1}{2}\log_2\left(1+\frac{\left(|g_{n_1,1}|^2+|g_{n_2,1}|^2\right)\alpha_1^2}{\left(|g_{n_1,1}|^2+|g_{n_2,1}|^2\right)\alpha_2^2+1/\rho}\right) \geq R_1 \right\} \tag{19}$$

Third, the relay combination with the best channel conditions to user with low-QoS is selected in Ψ_r. The final relay combination can be obtained as

$$\left(n_1^*, n_2^*\right) = \arg\max_{(n_1,n_2)} \left\{ |g_{n_1,2}|^2 + |g_{n_2,2}|^2, (n_1,n_2) \in \Psi_r \right\} \tag{20}$$

Further analyze the time complexity of the proposed two relay selection strategies and two existing relay selection strategies. The time complexity of Max-min relay selection strategy, Two-stage relay selection strategy and Max-min dual relay selection strategy are all $O(N)$. The time complexity of Triple dual relay selection strategy is $O(N^2)$. Compared with the two existing relay selection strategies, the proposed max-min dual relay selection strategy does not increase the time complexity. Although the proposed Triple dual relay selection strategy increases the time complexity, the system outage performance is significantly improved.

4. NUMERICAL AND SIMULATION RESULTS

In this section, the outage performance of the proposed max-min dual relay selection strategy and triple dual relay selection strategy for cooperative NOMA networks is evaluated by using computer simulation.

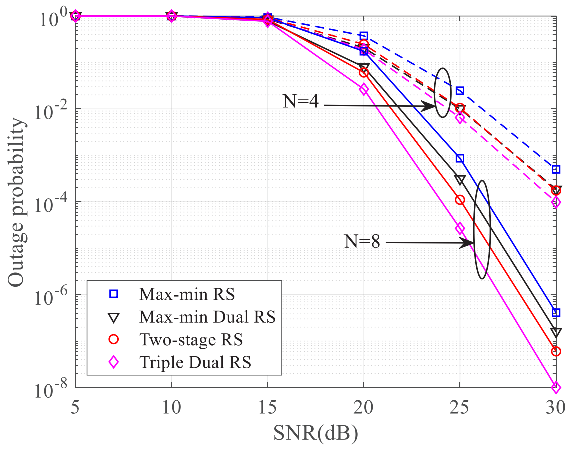

Fig.2 Impact of the relay numbers *N* on the outage performance of the different relay selection strategies.

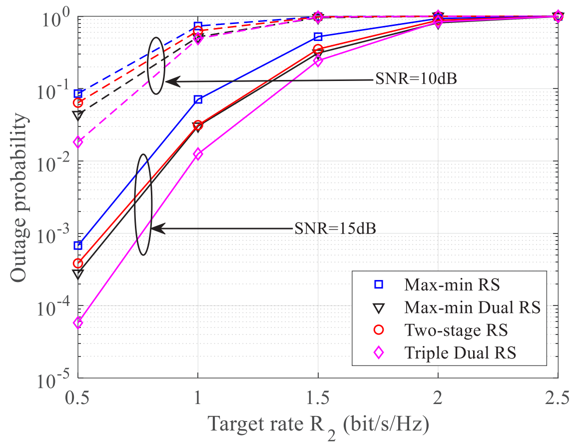

Fig.3 Impact of the R_2 on the outage performance of the different relay selection strategies.

Fig.2 shows the outage probability for the max-min dual relay selection strategy and triple dual relay selection strategy at the target data rate $R_1 = 0.5$ bits/s/Hz and $R_2 = 2$ bits/s/Hz, the power allocation factor $\alpha_1^2 = 3/4$ and $\alpha_2^2 = 1/4$, respectively. It can be seen from the figure that the proposed max-min dual relay selection strategy can remarkably enhance the outage performance compared to the max-min relay selection strategy, and the triple dual relay selection strategy can further enhance the outage performance compared to two-stage relay selection strategy7). As the number of relays increases, the outage probability of all relay selection strategies gradually decreases. The reason for this performance gain is that the increase in the number of relays increases the possibility of relays with better channel conditions. This is also the reason why the performance of max-min dual relay selection strategy and two-stage relay selection strategy has a larger gap under the condition of a large number of relays.

Fig.3 shows the impact of R_2 on the outage performance of the different relay selection strategies at the target rate $R_1 = 0.5$ bits/s/Hz, the number of relays $N = 6$, the power allocation factor $\alpha_1^2 = 3/4$ and $\alpha_2^2 = 1/4$. It can be observed in the figure that the outage performance of the two dual relay selection strategies proposed are better than the two single relay selection strategies, and triple dual relay selection strategy clearly has the lowest outage probability. The outage probability of all relay selection strategies increases gradually with the increase of R_2. Under the condition of low R_2, there is a significant gap of outage probability between triple dual relay selection strategy and two single relay selections.

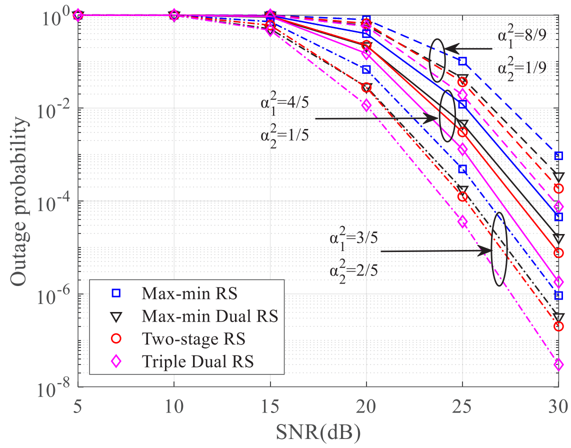

Fig.4 Impact of the α_1^2 and α_2^2 on the outage performance of the different relay selection strategies.

In Fig. 4, the impact of α_1^2 and α_2^2 on the outage performance of the different relay selection strategies at the target data rate $R_1 = 0.5$ bits/s/Hz and $R_2 = 2$ bits/s/Hz, the number of relays $N = 6$. It can be seen from the figure that the power allocation factor has a significant impact on the system outage probability. Under the condition of $\alpha_1 \geq \alpha_2$, the system outage probability is significantly reduced after more power is allocated to a user with low-QoS. This is caused by allocating too much power to low-rate and high-QoS users. Reasonable power allocation for users can further reduce the outage probability of the system. It should be pointed out that the outage probability of the triple dual relay selection strategy proposed is the lowest regardless of the power allocation.

5. CONCLUSION

In this paper, we have studied the impact of relay selection on cooperative NOMA networks, proposed max-min dual relay selection strategy and triple dual relay selection strategy. Simulation results demonstrate that the proposed two relay selection strategies can further reduce the outage probability of the system. Although the proposed relay selection strategies increase the complexity to some extent, it can significantly reduce the system outage probability, especially the triple dual relay selection strategy, and with the increase of the data processing capacity of the computer, the increased complexity can be ignored. Furthermore, the impact of the relay number, the power allocation factor, and the target data rate of users on the performance was discussed. It can be concluded that the distribution of power has the greatest impact on outage performance, which can be investigated as a future work.

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