Performance Evaluation for Cooperative NOMA Using Combined Relay Selection Scheme

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Research Article

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Nidhi Chaudhary · N. P. Singh · Gaurav Verma

**Abstract** Effective relay selection in non-orthogonal multiple access (NOMA) is an efficient way to attain a significant performance gain in terms of achieving a high system capacity, ergodic sum rate and a low outage probability. This become more promising when NOMA is treated under cooperation of more than one relay nodes. Relay selection performs well when the source node has an accurate and updated channel state information (CSI). As having perfect CSI is very difficult, therefore the relay selection with continuous time varying CSI is of paramount importance. This paper proposes a combined relay selection (CRS) scheme with time varying CSI which uses failure probability as an important criterion to improve the overall performance of cooperative NOMA system. The proposed approach is compared with most commonly used relay selection schemes: round robin relay selection (RRRS), opportunistic relay selection (ORS) and balanced criteria relay selection (BCRS) scheme. The simulation results show that proposed scheme outperforms the RRRS, BCRS and ORS in terms of ergodic sum rate, system capacity and outage probability.

**Keywords** Non-orthogonal multiple access (NOMA), round robin relay selection (RRRS), balanced criteria relay selection (BCRS), opportunistic relay selection (ORS), system capacity, sum rate and outage probability.

1 Introduction

In recent years, the network traffic has increased significantly as advanced services like device-to-device communication (D2D) and Internet of Things (IOTs) are introduced by fifth-generation (5G) communication [1]. So, there is a challenge for the existing network to accommodate all these services under this limited spectrum availability. To improve spectrum efficiency, a relay assisted (RA) network with relay selection has gained lot of interest [1-7]. Non-orthogonal multiple access (NOMA) is a promising concept to improve the spectrum efficiency by making an efficient use of available spectrum [8-11]. The key idea behind NOMA is to serve multiple users at single frequency with different power levels [11]. To balance user fairness in NOMA, the user with better channel conditions is allocated less power as compared to the user with poor channel conditions [9].

The system performance degrades if the distance between source and destination is greater than their transmission range [4]. This degradation in performance is due to fading effect as the source node can not directly communicate with the destination node. To overcome this issue researchers have introduced a cooperative network with one or more than one relay to improve the overall system performance [10]. To achieve the desired performance, relay selection is an indispensable criteria for cooperative network. There has been little research thus far that focuses on different relay selection schemes [11-20]. According to design issue, relay selection can be categorized into two types: one-way relay selection and two-way relay selection [5]. A two-way amplify and forward relay network is proposed [6] that maximize the worse receiver SNR of two end user.

Based upon transmission mode, relay selection scheme can be classified into three types: Amplify and Forward (AF), decode and forward (DF), and compress and forward (CF) [12-14]. In the AF relay selection
scheme, the relay node simply retransmits the amplified version of the received message signal to the destination [13]. In DF relaying method, the relay node first decodes the message received from the source and retransmits the new encoded message to the destination node [14]. In the CF relay selection scheme, the relay node neither amplifies nor decodes the message but simply quantizes the received message and transmits the encoded version of the quantized message to the destination [14].

According to various constraint functions such as Harmonic mean and throughput, various relay selection schemes have been discussed by authors in [15-19]. A new cooperative communication protocol has been investigated [15] which can help the source node to select the best relay node based upon the harmonic mean function of its (source-to-relay and relay-to-destination) channel gains. In this scheme the relay with the largest harmonic mean can be used for better transmission. The throughput is another important parameter to measure the network performance. In [18], a relay node that has high SNR as compared to predefined throughput is selected for message transmission.

A partial relay selection scheme for cooperative NOMA has been discussed [20] to show that the power allocation factor and the number of relay nodes have a great impact on outage performance. To further reduce the complexity in NOMA when performing power allocation, the authors [21] investigated a buffer-aided relay selection policy avoiding the need for channel state information at the transmitter. To improve spectral efficiency and outage probability a cooperative relay selection with NOMA has been proposed [22], where the relay node is selected in a max-min manner. This is done to satisfy the QoS of the user. A cooperative buffer-state-based relaying scheme using NOMA is proposed [23], which not only minimizes the outage probability but also reduces the average packet delay.

In the existing literature on NOMA, the researchers only focused on static CSI for relay selection. However, in real time problem channel varies continuously with time and a time gap exists between relay selection and data transmission. This shows that CSI used in relay selection is an outdated version of CSI used in data transmission. Due to this, the selected node may not actually be best for data transmission.

To overcome this problem, this paper proposes a combined relay selection scheme with continuous time varying CSI in cooperative NOMA system. In the proposed scheme, relay selection is done based on the channel coefficient between source-relay-destination and success rate of selected relay node for data transmission in previous time slot. The N best relay is selected out of the decodable relay, concerning their channel condition. Further, the proposed scheme is compared with the available RS schemes (i.e. opportunistic relay selection, round-robin relay selection, and balanced relay selection) in terms of ergodic sum rate, outage probability and system capacity.

The composition of this paper is as follows: The section 2 discusses the existing relay selection schemes. In section 3, we present system model of proposed scheme. Obtained simulation results are described in section 4 and finally this paper is concluded in section 5.

2 The existing relay selection scheme

Selecting the relay node for a cooperative communication system is an important task because the relay nodes play an important role in exchanging the information between source and destination nodes [15]. Not only source to destination performance is necessary in relay selection but overall system performance should also be considered. So, appropriate relay selection improves the overall system performance. Some related relay selection methodologies are discussed below.

Round Robin relay selection

For providing equal opportunity to each user, a round-robin relay selection scheme can be applied. In this scheme all the nodes having an equal probability for the selection of relay nodes irrespective of their channel condition [9]. Different from other schemes, in the round-robin RS scheme each relay node is selected from the available group for re-transmission of the received message from the base station in a cyclic manner. The BS first selects node 1, then node 2, and so on till M. In this scheme relay is selected in turn by rotating relay request to each node, which can be described as:
In this scheme, BS sends the superimposed message to the selected relay in the first hop, and then the selected relay decodes the received message, re-encode and forward the reconstructed message to the destination node in the second hop. The major drawback of using this scheme is that it degrades the system performance by assuming each node has a similar channel condition.

Balanced relay selection

To balance the system performance and resource utilization, a balanced relay selection scheme [23] can be applied. In a Balanced RS Scheme, relay selection depends upon the channel characteristics in the current time slot as well as mean channel strength in previous time slots. The balanced factor $Q_a$ and $Q_b$ take place in the relay selection procedure. Where $Q_a$ and $Q_b$ are described [23] as $\frac{|\alpha_k|^2}{E[|\alpha_k|^2]}$ and $\frac{|\beta_k|^2}{E[|\beta_k|^2]}$ in which $\alpha_k$/$\beta_k$ is the channel characteristics during current time slot and $E[|\alpha_k|^2]/E[|\beta_k|^2]$ defines the mean channel strength in previous time slots. The criterion for best relay selection can be written as:

$$\max\{\min\{Q_a|\alpha_{SRk}|^2, Q_b|\beta_{rdj}|^2\}, k \in K\}$$  (2)

The system performance of the Balanced RS scheme is better than the round-robin scheme but worse than the opportunistic RS scheme.

Opportunistic relay selection

This relay selection scheme is capable to choose the best relay among the available ‘M’ candidate relay node which participates in the communication process take place between the source node and destination node [18]-[26]. In this selection process, the channel state information is obtained by each relay which gives the idea about the source to relay and relay to the destination channel. Channel state information (CSI) based upon channel fading, shadowing between source-relay-destination nodes. Relay selection criteria based upon CSI is described as:

$$\max\{\min\{|\alpha_{SRk}|^2, |\beta_{rdj}|^2\}, k \in K\}$$  (3)

where $K = \{1, \ldots, i, \ldots, M\}$ represents the number of relay nodes which participate in the selection process and $\alpha_{SRk}$ and $\beta_{rdj}$ represents the channel condition among source – relay – destination nodes.

3 System model and proposed relay selection scheme

In this section, we introduce our proposed system model based on two-hop transmission, consisting a single source node, M number of relay nodes and two destination nodes ($d_1$ and $d_2$). It is assumed that there is no direct communication between source node and the destination nodes, therefore the relay node is used for efficient transmission and all the nodes are operated in half-duplex mode: $P_1$ and $P_2$ are the transmission powers allocated to the base station and relay nodes. The relay node work in Decode and Forward manner and complete transmission can be divided into two steps. The channels from base station (s) to relay $k$ and relay $k$ to destination $i$ is denoted as $\alpha_{SRk}$ and $\beta_{rdi}$ respectively where, $k \in \{1, \ldots, \ldots, M\}$ and $i \in \{1,2\}$. Assume that all the transmission channel of the system experience independent Rayleigh fading and the channel characteristics are time varying. It is also considered that all relay nodes knows the channel state information (CSI) of $\alpha_{SRk}$ and $\beta_{rdi}$.

The overall transmission consists of two time slot. During first time slot, base station $S$ sends a superimposed signal, $X_t = (\sqrt{P_1}a_1\times x_1 + \sqrt{P_2}a_2\times x_2)$ to the selected relay node, where $a_1$ and $a_2$ denotes the power allocation coefficient with $\sum_{i=1}^{2}a_i = 1$, and $x_1$ and $x_2$ are the corresponding message signal for destination nodes. Similar to conventional NOMA, more power is allocated to far user and less power is allocated to near user.

During the second time slot, assume that relay node is selected based upon strongest transmission channel condition using opportunistic relay selection. After that selected relay decoded the received message and then reconstruct it into new NOMA signal and then forward it to the required destination nodes.
The received signal at the relay node may be expressed as:

\[ Y_RK = \alpha SRK \left( \sqrt{a_1P_t}x_1 + \sqrt{a_2P_t}x_2 \right) + n_{RK} \]  

where \( n_{RK} \) is additive white Gaussian noise (AWGN) with zero mean and variance \( \sigma^2_{kj} \) at the node \( k \) during first hop. Now assume that destination \( d_1 \) is far user and \( d_2 \) is near user. So, according to NOMA principle, the relay \( k \) first decode the \( x_1 \) by treating \( x_2 \) as noise. A successive interference cancellation (SIC) scheme is used at relay node for decoding of the signal. The corresponding SINR and SNR at relay \( k \) for \( x_1 \) and \( x_2 \) are given as:

\[ \gamma_{RK}, x_1 = \frac{|\alpha_{SRK}|^2 a_1 \rho_k}{|\alpha_{SRK}|^2 a_2 \rho_k + 1} \]  

and

\[ \gamma_{RK}, x_2 = |\alpha_{SRK}|^2 a_2 \rho_k \]  

where \( \rho_k = \frac{P_t}{\sigma^2_{kj}} \) represents the transmit SNR.

During the second time slot, the selected relay \( k \) with strongest channel condition decodes the message signal using SIC, then reconstruct it into new NOMA signal

\[ X_{RK} = (\sqrt{P_t}b_1 x_1 + \sqrt{P_t}b_2 x_2) \]  

where \( \Sigma_{i=1}^2 b_i \) represents the new power allocation coefficient and then forward it to the destination nodes.

The signal received at destination \( j \) can be described as [29]:

\[ y_{dj} = \beta_{Rkdj} \left( \sqrt{P_t}b_1 x_1 + \sqrt{P_t}b_2 x_2 \right) + n_{Rkdj} \]  

where \( n_{Rkdj} \) is the AWGN noise with zero mean and \( \sigma^2_{kj} \) variance. For accurate signal decoding, \( d_1 \) will decode the received signal with SINR because more power is allocated to user 1 and \( d_2 \) will decode the received signal with simple SNR. The corresponding SINR and SNR at user \( j \) is represented as [25]:

\[ \gamma_{d1}, x_1 = \frac{|\beta_{Rkd1}|^2 b_1 \rho_{k1}}{|\beta_{Rkd2}|^2 b_2 \rho_{k1} + 1} \]  

\[ \gamma_{d2}, x_1 = \frac{|\beta_{Rkd1}|^2 b_1 \rho_{k1}}{|\beta_{Rkd2}|^2 b_2 \rho_{k2} + 1} \]  

and

\[ \gamma_{d2}, x_2 = |\beta_{Rkd2}|^2 b_2 \rho_{k2} \]  

where \( \rho_{kj} = \frac{P_t}{\sigma^2_{kj}} \) represents the transmit SNR during transmission.

To improve the performance of overall communication network in terms of sum rate and outage probability under time varying channel conditions, this paper proposes a combined relay selection (CRS) which take the advantages of two different kind of existing techniques namely: opportunistic relay selection and relay selection on the basis of performance. It is assumed that channel condition among base station, relay and destination nodes are continuously time varying. Sometimes, it is difficult to select the best relay due to lack of accurate information about channel state. So, to improve resource utilization it is necessary to propose a new relay selection scheme which not only considers the channel condition between source and relay but also consider the failure probability of relay node.

The selected relay by using traditional opportunistic relay selection (ORS) scheme cannot adapt the channel variation during data transmission which degrades the system performance continuously. So, to improve the system performance, we propose a combined relay selection scheme which not only consider the channel
condition among source-relay-destination but also consider their previous performance for relay selection. In this scheme total transmission is divided into two phases: Relay Selection Phase and Data forwarding Phase.

Relay Selection Phase: In proposed CRS scheme relay selection is further divided into two phases. During first phase relay selection is done based upon channel prediction as follows:

- BS sends the data message to each relay, after receiving the message all relay nodes decode it. Relay nodes that decode the message correctly are the candidate for further processing.
- N best relays are selected out of decodable relay based on maximal channel strength. The criterion for finest relay selection can be presented as:

\[
\max \{ \min \{ |\alpha_{SR_k}|^2, |\beta_{R_kd_j}|^2 \}, k \in (1, ..., M) \} \quad (11)
\]

where relay k with maximum CSI is selected.

During second phase, after selecting the N finest relay, a history based method is applied to find the \(i^{th}\) finest node among the N selected node. According to their previous history a performance based relay selection scheme is applied. The relay selection algorithm can be written as:

```
history table: [relay id, failure probability]
threshold: standard value

Selected relay = i
```

where n is the opportunistic selected relay and failure probability (\(f_p\)) can be defined as:

\[
f_p = \frac{\text{total no. of communication-success rate}}{\text{total no. of communication}}
\]

In performance based relay selection, finest relay is selected based on their success rate. By using this combined relay selection, the time for redoing the relay selection is reduced and the overall performance of cooperative communication is improved.

Data forwarding phase: the selected relay forward the received message to the destination.

4 Performance evaluations

This section provides simulation results in order to evaluate the achievable performance of combined relay selection scheme, which is compared with RRRS [9], BCRS [23] and ORC [25]. For simulation, similar to [25], the following parameter are set as: the number of relay node are taken to be \(M = 5\), the average SNR varies from \(\gamma = 0\) to 20 dBm. The channel coefficients between base station and relay nodes are taken to be \(\alpha_1 = 7, \alpha_2 = 12, \alpha_3 = 14, \alpha_4 = 6, \alpha_5 = 4\). The channel coefficients from relay node \(i\) to destination nodes \(d_1\) and \(d_2\) are taken to be \(G_1 = G_2 = G_3 = G_4 = G_5 = 8\) and \(h_1 = h_2 = h_3 = h_4 = h_5 = 5\) respectively, where power allocation factors are assumed as \(a_1 = b_1 = 0.9\) and \(b_2 = a_2\).

A sample simulation is made to analyze the solution of outage probability in the proposed scheme. For a given relay i, only if achieved target rate \(R_1\) and \(R_2\) for user 1 and 2 are greater or equal to their preset target rate threshold \(R_{si}\), the relay can successfully decode the message \(x_1\) and \(x_2\), where \(R_1\) and \(R_2\) can be described as:

\[
R_1 = \frac{1}{2} \log_2 \left( 1 + \frac{|\alpha_{SR_k}|^2 a_1 \rho_k}{|\alpha_{SR_k}|^2 a_2 \rho_k + 1} \right) \quad (12)
\]
\[ R_2 = \frac{1}{2} \log_2 \left( 1 + \frac{|\alpha_{SR_k}|^2 a_2 \rho_k}{a_2 \rho_k} \right) \]  

(13)

The outage probability can be described as:

\[ P_{out} = 1 - P_r \left\{ R_1 > 2^{NR_{s1}} - 1, R_2 > 2^{NR_{s2}} \right\} \]  

(14)

To reduce complexity assume \( \omega_i = 2^{NR_{si}} \) and the exact expression for \( X_i \) can be written as:

\[ X_1 = P_r \left\{ \min \{ \gamma_{R_k} x_1, \gamma_{d_1} x_1, \gamma_{d_2} x_2 \} > \omega_1 \right\} \]  

(15)

and

\[ X_2 = P_r \left\{ \min \{ \gamma_{R_k} x_2, \gamma_{d_2} x_2 \} > \omega_2 \right\} \]  

(16)

In Fig. 2 and Fig. 3, four relay selection scheme are compared in terms of outage probability by varying transmit SNR \( \gamma \) in the range from 0 to 20 dBm. where power allocation factors are \( a_1 \) and \( b_1 = 0.9 \) and predefined threshold, similar to [29], \( \omega_1 = \omega_2 = 0.5 \). It can be clearly observed in these figure that the proposed CRS scheme provide less outage as compared to the three existing RS scheme.

As observed in Fig. 4, the proposed approach has low outage among all four RS scheme. The performance of the outage probability improves as the channel gain improves and the threshold decreases.

Fig. 2 Comparison of outage probability of user 1 for proposed scheme with three existing RS scheme.

Fig. 3 Comparison of outage probability of user 2 for proposed scheme with three existing RS scheme.

Fig. 4 Outage probability vs. transmit SNR.

Fig. 5 observe the significant improvement in term of sum rate for CRS scheme as compared to RRRS, BCRS and ORS. This signifies the better chances of spectrum utilization in the proposed approach. We find the
ergodic sum rate performance versus transmit SNR for our proposed scheme while power allocation factor are taken to be  $a_1 = 0.9$ and $a_2 = 1 - a_1$, as well as $b_1 = a_1$ and $b_2 = a_2$.

**Fig. 5** The ergodic sum rate vs. transmit SNR.

Fig. 6 and Fig. 7 show the achievable capacity of user 1 and user 2 for proposed CRS scheme, round robin relay selection, balanced criteria and opportunistic relay selection schemes. The Figures clearly shows that the proposed scheme has better achievable capacity among all of them and the round robin has the worst criteria.

**Fig. 6** Achievable capacity of user 1 vs. transmit SNR.

**Fig. 7** Achievable capacity of user 2 vs. transmit SNR.

**5 Conclusion**

In order to reduce the spectrum scarcity in wireless communication, it is very important to investigate an effective resource utilization scheme with relay selection in NOMA. In this scheme, the key idea behind the selection of relay node not only consider the channel gain among source, relay nodes and destination but also considers the failure probability of data transmission based upon their previous history. The presented results show that the performance of proposed scheme in terms of outage probability, ergodic sum rate and achievable capacity gains a significant improvement compared to the round robin, balance criteria and opportunistic RS.

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Figures

**Figure 1**

System model of Cooperative Communication with relay selection scheme.
Figure 2

Comparison of outage probability of user 1 for proposed scheme with three existing RS scheme.
Figure 3

Comparison of outage probability of user 2 for proposed scheme with three existing RS scheme.
Figure 4

Outage probability vs. transmit SNR.
Figure 5

The ergodic sum rate vs. transmit SNR.
Figure 6

Achievable capacity of user 1 vs. transmit SNR.
Figure 7

Achievable capacity of user 2 vs. transmit SNR.