PAPER

Sum Rate Maximization for Cooperative NOMA with Hardware Impairments

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SUMMARY This paper investigates the sum rate (SR) maximization problem for downlink cooperative non-orthogonal multiple access (C-NOMA) systems with hardware impairments (HIs). The source node communicates with users via a half-duplex amplified-and-forward (HD-AF) relay with HIs. First, we derive the SR expression of the systems under HIs. Then, SR maximization problem is formulated under maximum power of the source, relay, and the minimum rate constraint of each user. As the original SR maximization problem is a non-convex problem, it is difficult to find the optimal resource allocation directly by tractional convex optimization method. We use variable substitution method to convert the non-convex SR maximization problem to an equivalent convex optimization problem. Finally, a joint power and rate allocation based on interior point method is proposed to maximize the SR of the systems. Simulation results show that the algorithm can improve the SR of the C-NOMA compared with the cooperative orthogonal multiple access (C-OMA) scheme.

key words: cooperative non-orthogonal multiple access, sum rate, resource allocation, hardware impairments, interior-point

1. Introduction

5G large connection Internet of Things (IoT) mass machine communication needs to support a connection number density of 1 million per square kilometer, which requires low cost, low signaling overhead, low latency, and low power consumption. Non-orthogonal multiple access (NOMA), is an core key technology of 5G new air interface, which is expected to solve the above problems [1]. The main feature of NOMA is to allow multiple users to share the same time, frequency, and code resources with different power allocation according to their channel conditions. At the receiver, the successive interference cancellation (SIC) technology is used to decode the superimposed information. NOMA can achieve higher spectral efficiency, higher cell edge throughput, lower transmission latency, enhanced user fairness, support more number of users compared with orthogonal multiple access (OMA) [2].

Cooperative non-orthogonal multiple access (C-NOMA) has been extensively studied to improve the capacity and reliability of wireless communication networks in [3]–[9]. Considering the information of the primary user and the secondary user were transmitted through the NOMA relay, a new two-slot NOMA relay-assisted spectrum shar-

ing scheme was proposed in [3]. [4] studied relay selection scheme of a cooperative NOMA network. The outage probability was derived under fixed and adaptive power allocation at the relay. [5] investigated a dual-user multi-relay C-NOMA network with distributed space-time coding, and proposed two dual-relay selection strategies with fixed and dynamic power allocation. [6] studied the NOMA downlink relay transmission. The macro base station firstly used NOMA to transmit to a group of relays, and then all relays used NOMA to transmit the data they received to the mobile terminal users. An optimal power allocation was proposed for BS and relay to maximize the total throughput provided to end-users. [7] studied NOMA amplification and forwarding (AF) relay networks, where joint power allocation and relay beam-forming design were considered. In [8], a novel non-orthogonal cooperative multiple access scheme was proposed to ensure the secure transmission of data for specific users. With the emphasis on external eavesdroppers and untrusted relays, a safe beam-forming algorithm was used to maximize the security rate of the systems in [9].

The works in [3]–[9] have assumed ideal hardware conditions. In practical cooperative NOMA systems, the transceivers of the BS node, the relay node, and the user node suffer from different types of hardware impairments (HIs), including in-phase/quadrature-phase imbalance (IQI), nonlinear amplifiers equivalent noise and radio frequency circuit noise [10]–[12]. The performance analysis of C-NOMA system with HIs is just at the initial stage of research [13]–[18]. [13] studied the impact of quantifying residual hardware impairments (RHIs) based on a multi-users C-NOMA AF relaying network. The authors derived an accurate and asymptotic expressions of the outage probability in closed-form. Furthermore, [14] investigated the impact of transceiver hardware impairments based on multi-users C-NOMA AF relaying network under a universal fading channel, and proposed two representative NOMA schemes. [15] studied the outage probability of NOMA systems under a single-carrier NOMA system with IQI hardware impairments. The energy harvesting (EH) under non-ideal channel state information in the multi-relay C-NOMA systems was analyzed in [16], and the closed-form expression of its outage probability was derived. The authors in [17] considered an unmanned aerial vehicle (UAV)-aided NOMA multi-way relaying networks (MWRNs), and derived the analytical expression for the achieve sum-rate. [18] researched an ambient backscatter NOMA system in the presence a malicious eavesdropper, and gave the analyti-

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cal expressions for the outage probability and the intercept probability. These studies in [13]–[18] mainly analyzed performance indicators such as the outage probability and asymptotic rate of NOMA systems under hardware impairments. However, they did not consider to optimize the system performance from resource allocation perspective.

Different from the prior works in [3]–[9], we consider non-ideal hardware condition of downlink C-NOMA network. Furthermore, different from the analysis scheme proposed in [13] and [14], we analyse the impact of HIs in the resource allocation perspective. The analysis utilizes the generalized hardware impairments topology model of [13]. This paper researches the sum rate (SR) maximization of single-carrier C-NOMA network under hardware impairments condition of source, reliable half-duplex amplified-and-forward (HD-AF) relay, and multi-users. We propose to analyze the SR through Rayleigh fading channels. We first derive the SR maximization problem under quality of service (QoS) constraints, which is non-convex and difficult to obtain the solution. By utilizing variable substitution, the non-convex SR maximization problem is converted into an equivalent convex optimization problem. Next, a joint user admitted control, power allocation factor (PAF) and rate allocation algorithm based on the interior point method is proposed to maximize the SR, and the closed-form solution expressions for the PAF are derived. Simulation results show that the proposed resource allocation algorithm is superior to cooperative orthogonal multiple access (C-OMA) scheme in terms of system's SR and the number of system admitted users. Furthermore, we investigate the impact of relay location based on two schemes.

The remaining sections are organized as follows: Sect. 2 describes the system model of C-NOMA with hardware impairments. Section 3 analyzes SR optimization problem with user admission control. Numerical results are provided in Sect. 4. The conclusion is presented in Sect. 5.

2. System Model

We consider a downlink NOMA-based half-duplex (HD) relay network consisting of a source node base station S , a half-duplex relay node R , and user nodes $U_n (n = 1, \dots, N)$ as Fig. 1. We assume that each user is equipped with a single antenna. Due to obstacles and severe shadowing, there is no direct link between the BS and the user. The base station first transmits the signal to the relay node, and then the relay amplifies and forwards the signal to the user according to the AF protocol. The channels from S to R and R to U follow independent but differently distributed (i, n, i, d) Rayleigh fading.

In the cooperative NOMA network based on the AF protocol, the communication process is divided into two time slots. Next, we introduce the AF protocol for C-NOMA as follows.

Fig. 1 System model of C-NOMA.

2.1 First Slot

The source node S sends a superimposed signal $\sum_{n=1}^N \sqrt{\alpha_n P_S} x_n$ to the relay node R . The signal received by the relay node R is expressed as:

$$y_R = h_S \left(\sum_{n=1}^N \sqrt{\alpha_n P_S} x_n + \eta_{SR} \right) + n_R \quad (1)$$

Where $h_S = g_{S,R} \cdot PL^{-1}(d_{SR})$ is the channel gain from the S to the R link. $g_{S,R}$ denotes the small-scale Rayleigh fading channel gain, and $PL^{-1}(d_{SR})$ is the path loss function between the S and R at distance d_{SR} [19]. P_S is the transmit power of the S , x_n and α_n are respectively the information and the power allocation factor by the S allocate to the user $U_n (n = 1, \dots, N)$. In addition, $n_R \sim \mathcal{CN}(0, \sigma_R^2)$ is the background noise at the R . The HIs at both the source node S and the relay node R is characterized as independent tortion noise η_{SR} , where $\eta_{SR} \sim \mathcal{CN}(0, \kappa_{SR}^2 P_S)$, and $\kappa_{SR} \triangleq \sqrt{\kappa_S^2 + \kappa_R^2}$ represents the sum error vector magnitudes (EVMs) from the S to the R link, where κ_S and κ_R severally characterizes the EVMs at the S and the R .

2.2 Second Slot

In the second time slot, the relay node R amplifies the received signal y_R with amplification factor β , and the amplification gain factor is given as follows.

$$\beta = \sqrt{\frac{P_R}{(1 + \kappa_{SR}^2) P_S |h_S|^2 + \sigma_R^2}} \quad (2)$$

Where P_R is the transmission power of relay R . The n -th user U_n receives the signal transmitted by the relay can be express as:

$$\begin{aligned} y_{U_n} &= h_{R,n} (\beta y_R + \eta_{R,n}) + n_{U_n} \\ &= h_{R,n} \beta \left(h_S \left(\sum_{n=1}^N \sqrt{\alpha_n P_S} x_n + \eta_{SR} \right) + n_R \right) + h_{R,n} \eta_{R,n} + n_{U_n} \\ &= \beta h_S h_{R,n} \sqrt{P_S} \left(\sum_{k=1}^{n-1} \sqrt{\alpha_k} x_k + \sqrt{\alpha_n} x_n + \sum_{j=n+1}^N \sqrt{\alpha_j} x_j \right) \\ &\quad + \beta h_S h_{R,n} \eta_{SR} + h_{R,n} \eta_{R,n} + \beta h_{R,n} n_R + n_{U_n}. \end{aligned} \quad (3)$$

Where $h_{R,n} = g_{R,U_n} \cdot PL^{-1}(d_{RU_n})$ is the channel gain from the R to the U_n link. g_{R,U_n} denotes the small-scale Rayleigh fading channel gain, and $PL^{-1}(d_{RU_n})$ is the path loss function between the R and U_n at distance d_{RU_n} , and $n_{U_n} \sim \mathcal{CN}(0, \sigma_{U_n}^2)$ is the Additive white Gaussian noise (AWGN) at U_n . Similarly, the independent distortion noise $\eta_{R,n} \sim \mathcal{CN}(0, \kappa_{RU_n}^2 P_R)$ denotes the HIs at both R and U_n . Moreover, $\kappa_{RU_n} \triangleq \sqrt{\kappa_R^2 + \kappa_{U_n}^2}$ ($n = 1, \dots, N$) represents the sum EVMs of the R to U_n link. For simplicity, we assume $\kappa_{RU}^2 \triangleq \kappa_{RU_n}^2$. Without loss of generality, it's the ideal model without HIs when invoking $\kappa_{SR}^2 = \kappa_{RU}^2 = 0$ into (2) and (3).

It's assumed that the user's channel gains are ordered to satisfy $|h_{R,1}|^2 \leq \dots \leq |h_{R,N}|^2$. User U_n firstly decodes weak users ($k < n$) and the interference caused by U_k can be cancelled from the received signal by utilizing SIC, while strong users ($j > n$) signals are regarded as interference. The Signal interference to noise ratio (SINR) of U_n decoded U_k can expressed as:

$$\gamma_{k \rightarrow n} = \frac{\alpha_k P_S \beta^2 |h_S|^2 |h_{R,n}|^2}{\beta^2 |h_{R,n}|^2 \left(\left(\sum_{j=k+1}^N \alpha_j + \kappa_{SR}^2 \right) P_S |h_S|^2 + \sigma_R^2 \right) + \kappa_{RU_n}^2 P_R |h_{R,n}|^2 + \sigma_{U_n}^2}, \quad (4)$$

Then the SINR of users after interference elimination of weak users ($k < n$) is:

$$\gamma_{n \rightarrow n} = \frac{\alpha_n P_S \beta^2 |h_S|^2 |h_{R,n}|^2}{\beta^2 |h_{R,n}|^2 \left(\left(\sum_{j=n+1}^N \alpha_j + \kappa_{SR}^2 \right) P_S |h_S|^2 + \sigma_R^2 \right) + \kappa_{RU_n}^2 P_R |h_{R,n}|^2 + \sigma_{U_n}^2}, \quad (5)$$

Substitute expression (2) into (5) for simplification to obtain the SINR of the receiver U_n after SIC :

$$\gamma_n = \frac{\alpha_n K_n}{\left(\sum_{j=n+1}^N \alpha_j + M_n \right) K_n + L_n}. \quad (6)$$

where M_n , K_n , and L_n are given by

$$\begin{aligned} M_n &= \kappa_{SR}^2 + \kappa_{RU_n}^2 + \kappa_{SR}^2 \kappa_{RU_n}^2, \\ K_n(P_S, P_R) &= P_S |h_S|^2 P_R |h_{R,n}|^2, \\ L_n(P_S, P_R) &= (1 + \kappa_{SR}^2) \sigma_{U_n}^2 P_S |h_S|^2 + (1 + \kappa_{RU_n}^2) \sigma_R^2 P_R |h_{R,n}|^2 \\ &\quad + \sigma_R^2 \sigma_{U_n}^2, \end{aligned}$$

The rate r_n of U_n can be simplified as follows:

$$r_n = \frac{1}{2} \sum_{n=1}^N \log_2 \left(1 + \frac{\alpha_n K_n(P_S, P_R)}{\left(\sum_{j=n+1}^N \alpha_j + M_n \right) K_n(P_S, P_R) + L_n(P_S, P_R)} \right). \quad (7)$$

3. Sum Rate Maximization Problem

From the above discussion, the sum rate maximization problem of cooperative NOMA system with HIs is as follows:

$$\begin{aligned} \max_{P_S, P_R, \alpha_1, \dots, \alpha_N} \quad & \frac{1}{2} \sum_{n=1}^N \log_2 \left(1 + \frac{\alpha_n K_n(P_S, P_R)}{\left(\sum_{j=n+1}^N \alpha_j + M_n \right) K_n(P_S, P_R) + L_n(P_S, P_R)} \right) \\ \text{s.t.} \quad & C1 : 0 \leq P_S \leq P_S^{\max}, \\ & C2 : 0 \leq P_R \leq P_R^{\max}, \\ & C3 : \alpha_j \geq 0, j = 1, \dots, N, \\ & C4 : \sum_{j=1}^N \alpha_j = 1, \\ & C5 : r_n \geq r_n^{\min}, n = 1, \dots, N. \end{aligned} \quad (8)$$

where $C1$ indicates the maximum transmission power constraint condition of S , $C2$ denotes the maximum transmission power constraint condition of R , $C3$ shows the non-negativity of power, $C4$ is the total transmit power constraint of S , $C5$ indicates the minimum rate constraint for each user. The coefficient $\frac{1}{2}$ in objective function, takes into account the two-time slots required for transmission from S to U .

Since the objective function is non-convex, the problem (8) are non-convex optimization problems. Therefore, we cannot directly give the optimal solutions of (8). However, we will transform (8) into an equivalent convex problem through variable substitution. As the objective function in (8) monotonically increases with respect to P_S and P_R , we can see that the optimal solution to P_S and P_R should be $P_S^{\max}$ and $P_R^{\max}$. Then, problem (8) can be rewritten as

$$\begin{aligned} \max_{\alpha_1, \dots, \alpha_N} \quad & \frac{1}{2} \sum_{n=1}^N \log_2 \left(1 + \frac{\alpha_n K_n(P_S^{\max}, P_R^{\max})}{\left(\sum_{j=n+1}^N \alpha_j + M_n \right) K_n(P_S^{\max}, P_R^{\max}) + L_n(P_S^{\max}, P_R^{\max})} \right) \\ \text{s.t.} \quad & C1 : \alpha_j \geq 0, j = 1, \dots, N, \\ & C2 : \sum_{j=1}^N \alpha_j = 1, \\ & C3 : r_n \geq r_n^{\min}, n = 1, \dots, N. \end{aligned} \quad (9)$$

Therefore, we only need to find the optimal solution for the PAF. However, the SR problem is still non-convex problem with respect to the PAF. Next, we will change it into equivalent convex optimization problem by variable substitution. To solve the above problem, we describe the relationship between the PAF and rate by utilizing the following lemma as [20], and turn the problem (9) into a convex optimization problem.

Lemma 1: Let $I_n = M_n + \frac{L_n(P_S^{\max}, P_R^{\max})}{K_n(P_S^{\max}, P_R^{\max})}$ ($n = 1, \dots, N$), $I_{N+1} = 0$. the following equation stands for the transmit PAF regarding rate as variables:

$$\sum_{j=n}^N \alpha_j = \sum_{j=n}^N (I_j - I_{j+1}) \times e^{2 \ln 2 \sum_{k=n}^j r_k} - I_n. \quad (10)$$

Proof: Because $\gamma_n = \frac{\alpha_n}{\sum_{j=n+1}^N \alpha_j + I_n}$ and $r_n = \frac{1}{2} \log_2(1 + \gamma_n)$, then we can character the relation between rate and PAF as

$$e^{2 \ln 2 r_n} = \frac{\alpha_n + \sum_{j=n+1}^N \alpha_j + I_n}{\sum_{j=n+1}^N \alpha_j + I_n}. \quad (11)$$

if $n = N$, we have $e^{2 \ln 2 r_N} = \frac{\alpha_N + I_N}{I_N}$, α_N can be rewritten as

$$\alpha_N = I_N e^{2 \ln 2 r_N} - I_N, \quad (12)$$

if $n = N - 1$, we have

$$e^{2 \ln 2 r_{N-1}} = \frac{\alpha_{N-1} + \alpha_N + I_{N-1}}{\alpha_N + I_{N-1}}, \quad (13)$$

Substitute (12) into the denominator of (13), we have

$$\sum_{n=N-1}^N \alpha_n = I_N e^{2 \ln 2 (r_{N-1} + r_N)} + (I_{N-1} - I_N) e^{2 \ln 2 (r_{N-1})} - I_{N-1}. \quad (14)$$

Equations (12) and (14) satisfy Lemma 1 and we further use the recursion method to obtain the equivalent form of total power allocation factor constraint. According to the same scaling method in [21], condition $\sum_{j=1}^N \alpha_j = 1$ is equivalent to $\sum_{j=1}^N \alpha_j \leq 1$ when PAF obtains the optimal solution $(\alpha_1^*, \dots, \alpha_N^*)$. So far, C2 in problem (9) can be rewritten as

$$\sum_{j=1}^N (I_j - I_{j+1}) \times e^{2 \ln 2 \sum_{k=1}^{k=j} r_k} - I_1 - 1 \leq 0. \quad (15)$$

By utilizing Lemma 1, problem (9) is equivalent to the following rate allocation problem.

$$\max_{r_1, \dots, r_N} \sum_{n=1}^N r_n, \quad (16)$$

$$\text{s.t.} \quad \sum_{j=1}^N (I_j - I_{j+1}) \times e^{2 \ln 2 \sum_{k=1}^{k=j} r_k} - I_1 - 1 \leq 0, \quad (17)$$

$$r_n \geq r_n^{\min}, n = 1, \dots, N. \quad (18)$$

Lemma 2: (16)–(18) are convex optimization problems.

Proof: $e^{2 \ln 2 \sum_{k=1}^{k=j} r_k}$ is a convex function because $\exp(g(x))$ is convex if g is convex [22]. Furthermore, we have $|h_{R,1}|^2 \leq \dots \leq |h_{R,N}|^2$ and $I_n = M_n + \frac{L_n(P_S^{\max}, P_R^{\max})}{K_n(P_S^{\max}, P_R^{\max})}$ ($n = 1, \dots, N$).

Thus, we can get $I_1 \geq \dots \geq I_N$, then $\sum_{j=1}^N (I_j - I_{j+1}) \times e^{2 \ln 2 \sum_{k=1}^{k=j} r_k}$

is convex function because the non-negative weighted sum of convex functions is a convex function. Constraints (17)–(18) are convex sets, and the objective function is affine, then (16)–(18) are convex optimization problems.

By Lemma 2, we can use the interior-point method to give the optimal solution to (16)–(18). Next, a feasible condition is presented. Because the left-hand side of constraint (17) is an increasing function with the transmit rate, and the minimum transmit rate requirement for user n is $r_n^{\min}$ ($n = 1, \dots, N$).

Lemma 3: (16)–(18) have a feasible solution if and only if constraint (17) is satisfied.

From Lemma 1–3, the optimal PAF and rate allocation of each user can be obtained. The proposed SR maximization algorithm with Hardware impairments is shown in Algorithm 1.

Next, we provide the complexity analysis for algorithm 1 in the worst case. The complexity of computing the user admission control and the power allocation coefficient is $O(N)$, in which N represents the total number of users in the network. After user admission control, the complexity of problem (16)–(18) is $O(((x^2 y + x^3) y^{1/2}) \log(\frac{1}{\epsilon}))$ with $x = N$ variables and $y = (N + 1)$ constraints, where ϵ is the tolerance value of the interior point method [23]. Therefore, the overall complexity of Algorithm 1 is $O((N^{7/2}) \log(\frac{1}{\epsilon}))$.

Algorithm 1 Sum Rate Maximization Algorithm of Cooperative NOMA with Hardware impairments

Input: $P_S, P_R, N, \sigma_R^2, \sigma_{U_n}^2, r_n^{\min}$ ($n = 1, \dots, N$)

Initialization: set $num=0$ and I_n ($n = 1, \dots, N$), $I_{N+1} = 0$.

for all $i \in (1, \dots, N)$ **do**

if $\sum_{j=i}^N (I_j - I_{j+1}) \times e^{2 \ln 2 \sum_{k=i}^{k=j} r_k^{\min}} - I_i - 1 > 0$ **then**

$num = num + 1$

end if

end for

if $num < N$ **then**

set $K = num + 1$

for all $n \in (K, \dots, N)$ **do**

$$\alpha_n^* = \sum_{j=n}^N (I_j - I_{j+1}) \times e^{2 \ln 2 \sum_{k=n}^{k=j} r_k^*} - \sum_{j=n+1}^N (I_j - I_{j+1}) \times e^{2 \ln 2 \sum_{k=n+1}^{k=j} r_k^*} + I_{n+1} - I_n,$$

where $(r_K^*, \dots, r_N^*)$ is the optimal solution to (16)–(18) by interior-

point algorithm, moreover $\sum_{n=K}^N \alpha_n^* = 1$, $r_n^* = \frac{1}{2} \log_2(1 + \frac{\alpha_n^*}{\sum_{j=n+1}^N \alpha_j^* + I_n})$.

end for

return $SR^* = \sum_{n=K}^N r_n^*$

else

$SR^* = 0$

end if

Output: SR^* , admitted number of users : $N^* = N - num$.

4. Simulation Results

This section presents the simulation results to evaluate the performance of the resource allocation algorithm proposed by the C-NOMA system based on QoS with hardware impairments and compares C-NOMA scheme with the C-OMA scheme. Considering large-scale fading in the simulation, we compare the effects of transmission power and relay location on sum rate of the systems. The base station is set to be $(-50, 0)$ m, the relay is first set to be $(0, 0)$, and then we investigated the impact of relay location on NOMA system. The number of users is $N = 8$, and the users are randomly distributed within in $[30, 70] \times [-20, 20]$ m. The path loss is given by $128.1 + 37.6 \log_{10} d$ dB [24], where d is the distance in kilometers. The noise power spectral density is -70 dBm. The HI is set to be $k_{SR}^2 = k_{RU}^2 \cdot r_n^{\min} = 0.1 \text{bps/Hz}$ ($n = 1, \dots, N$). The simulation results are the average value after 1000 independent simulations.

Figure 2 describes the average sum rate of the proposed algorithm under different hardware impairments factors, e.g. 0, 0.1, 0.2. From the simulation results, as the level of hardware impairments increases, the performance of C-NOMA is significantly better than C-OMA.

Figure 3 depicts the comparison of the performance of the number of admitted users in C-NOMA and C-OMA affected by different hardware impairments under the mini-

sum rate constraint and different maximum transmission power. From the simulation results, the user tolerance performance of C-NOMA is significantly better than C-OMA, increasing respectively as 7%, 16%, 166% when $P_S^{\max}$ equals to 45 dBm. This is because C-NOMA can share the same spectrum resource, and C-OMA requires the spectrum to be equally divided and orthogonal, resulting in low spectrum utilization. This algorithm takes into account the admission control. When the power allocation is insufficient to satisfy the QoS requirements of all users in the current network, more users will be removed, and the system needs to allocate more power to the users with poor channel conditions to meet QoS requirements.

Figure 4 indicates the comparison of the average sum rate of C-NOMA and C-OMA versus Relay location from $(-30, 0)$ m to $(30, 0)$ m. It can be seen that the average sum rate of C-NOMA is better than C-OMA, and the best relay locations are given in it. Moreover, with the increase of system hardware impairments, the influence of the relay location on sum rate is gradually weakened. The reason is that there is an upper-floor to the hardware impairments level of the practical cooperation system.

Figure 5 shows average number of admitted users with different BS location. When the power allocation is insufficient to meet the QoS requirements of all users in the current network, users with poor channel conditions will not be admitted to transit. As the level of hardware impairments

Fig. 2 Average sum rate of two cooperative systems versus BS maximum transmission power.

Fig. 3 Average number of admitted users of two cooperative systems versus BS maximum transmission power ($r_n^{\min}=0.1 \text{bps/Hz}$, $P_R=30 \text{dBm}$, $R(0, 0)$).

Fig. 4 Average sum rate of two cooperative systems versus relay location ($r_n^{\min}=0.1 \text{bps/Hz}$, $P_S=34 \text{dBm}$, $P_R=30 \text{dBm}$).

Fig. 5 Average number of admitted users of two cooperative systems versus relay location ($r_n^{\min}=0.1 \text{bps/Hz}$, $P_S=34 \text{dBm}$, $P_R=30 \text{dBm}$).

increases, C-NOMA performs better than C-OMA, and accommodate more users.

5. Conclusions

This study investigated the sum rate maximization problem of cooperative NOMA with hardware impairments. By combining the power allocation factor and minimum rate constraint, an optimization algorithm based on the interior point method is proposed to maximize the sum rate. We further investigate the impact of relay location. The simulation results show that the proposed algorithm improves the sum rate and the number of admitted users compared with C-OMA under different HIs factors and relay location. One of the future work is to consider the sum rate maximization problem of SWIPT assisted C-NOMA system as [25].

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