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Role Switching and Power Allocation Technique for Mobile Users in Non-orthogonal Multiple Access[⋆]

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ABSTRACT

In this paper, role switching and power allocation schemes are proposed to tackle user mobility in non-orthogonal multiple access (NOMA) systems. A downlink transmission scenario is considered, where two highly mobile users, a cell center user and a cell edge user, are paired/served over the same channel resource using NOMA. In such high mobility scenarios, when these users come very close to, or even cross, each other, their channel gains may become similar or even violate the initial channel ordering when they were paired. This article refers to such condition as NOMA principle violation problem (NPVP). To solve this NPVP, optimized power role switching-NOMA (OPRS-NOMA) technique is proposed. Role switching technique is used to switch the roles of mobile users on the basis of their dynamic channel ordering. Furthermore, a power allocation scheme based on bisection search power optimization is presented to maximize the average sum capacity of mobile NOMA users. Random way point mobility model is considered for user mobility , where individual and sum capacity are used for performance evaluation. Simulation results show that OPRS-NOMA outperforms the conventional NOMA and orthogonal multiple access schemes.

1. Introduction

Existing orthogonal multiple access (OMA) schemes, where each user is allocated a dedicated radio resource block (RB), are unable to tackle the high connectivity demands of future networks due to the limited number of available channel resources. To this end, non-orthogonal multiple access (NOMA) has gained significant research interest as a promising multiple access technique [1], where multiple users can simultaneously share the same RB. Due to multi-user loading over the same channel resource, NOMA can achieve high spectral efficiency [2–4], and is proposed for inclusion in the 3GPP long-term evolution advanced (LTE-A) standard [5], where it is referred to as multi-user superposition transmission (MUST). Further, the NOMA technique has been adopted lately by the 3GPP release-16 standards (5G) [6] and it is mentioned as an important key enabler for massive Machine Type Communication (MTC); one of the main use cases of the Internet of things in 5G and beyond (B5G) [7–10].

NOMA for massive connectivity in 5G has been extensively covered through various surveys and a variety of NOMA schemes have been proposed by academic and industry in recent years [11–13]. However, power domain NOMA (referred simply as NOMA here) is considered in this work. In NOMA, multiple paired/grouped users are served over the same RB, where base station (BS) allocates different power levels to their signals in order to facilitate these users in performing efficient data recovery through successive interference cancellation (SIC).

The existing works on NOMA [14–16] mostly focus on the capacity maximization by considering static users. Majority of these works consider a basic two-user system, where a cell center user (CCU) having high channel gain is paired with a cell edge user (CEU) having low channel gain. The BS allocates different powers to these users, high power to CEU and low power to CCU, to enable data recovery at their receivers. As static users are considered, the user pairing and power allocations remain same for most of their communication session. However, if the paired users are mobile, a situation may occur when their channel ordering becomes opposite i.e., CCU's channel gain becomes lower than the CEU. Let $|h_1|^2$ and $|h_2|^2$ be the channel gains of paired CCU and CEU respectively, where $|h_1|^2 \gg |h_2|^2$. The BS allocates appropriate power levels to these users, and everything starts working. However, due to mobility, they can come very close, or even cross, each other, so that the channel gains could be $|h_1|^2 \approx |h_2|^2$ or $|h_1|^2 < |h_2|^2$. In this paper, this specific channel gains situation is termed as NOMA principle violation problem (NPVP).

The performance of mobility-aware networks is very important in cellular networks due to its impact on resource management, radio propagation and location management [17]. Recently, some research works [18, 19] considered UAV-Aided NOMA networks. The users considered in these works have on ground fixed locations and are considered static while the transmission to the users is through UAV(s).

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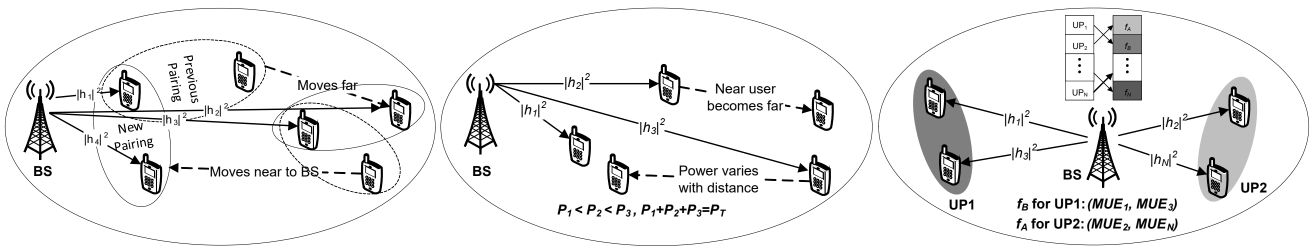


(a) (b) (c)

Figure 1: General issues of NOMA with user mobility in 5G (a) the user pairing problem when users have different channel gains. (b) the power allocation problem during mobility. (c) the efficient resource allocation for mobile users entering or leaving a cell.

However, a UAV NOMA network with mobile UAVs as users is less explored area and can be an interesting research direction where secure transmission along with the Quality of Service (QoS) requirements is guaranteed. More efficient techniques are required for UAV NOMA networks but these extensions are out of scope and have to be left for future work.

Even though, there are some recent research works like [20], where the users have heterogeneous mobility profiles in an ultra dense network (UDN) and ideally one user is entertained by only one BS with the capability to support connection for high-speed vehicles having speed up to 500 km/h. Further, the study shows that users under densely deployed networks have high handover rates and overheads due to mobility. Also, in [21], a NOMA protocol with orthogonal time frequency space (OTFS) modulation is proposed for users having heterogeneous mobility profiles to improve spectral efficiency. The high mobility users having weak channel gains are paired with the low mobility users having strong channel gains to implement NOMA. However, it is most likely that users with different speeds can have similar channel gains or reverse channel ordering at some point in time, which can violate the NOMA principle even if the users have different power levels. In such scenarios, one solution is to break these user pairs, and then find other users for adjusting them in new pairs. But, in high mobility scenarios, breaking existing pairs and re-making of new pairs may cause severe handover failures, which may affect the network performance significantly. Therefore, an efficient mobility aware NOMA technique is required that can manage the pairing of mobile users of different relative speeds without breaking and re-making pairs. This is important as the relative speeds of users will have a direct impact on the frequency of role switching and the associated power optimization.

1.1. Motivation and Contributions

Motivated by these issues, the mobility-aware NOMA protocol with role switching and power allocation is proposed in this work. A system model of two mobile users in a pair is considered to demonstrate the NPVP. The reason behind selecting two users in a pair is the high error probability and SIC complexity which increases with the increase in the number of users in a pair. However, the proposed technique can easily be generalized to multi-user scenarios.

To the best knowledge of authors, research on user pairing and power allocation in NOMA with user mobility is still lacking. Therefore, the work in this article focuses specifically on mobility issues in NOMA. The main contributions of the work are summarized as follows:

- To resolve NPVP in mobile environments, an optimized power and role switching-NOMA (OPRS-NOMA) technique is proposed in this paper. The role switching technique is first presented which changes the roles of CCU and CEU when their channel gains ordering is inverted due to mobility.
- Furthermore, an optimal power allocation technique is presented to maximize the sum capacity of these paired users.
- To validate the effectiveness of proposed techniques, random way point (RWP) mobility model is used for NOMA users. Individual and pair sum capacity of the users are analyzed and compared with conventional NOMA and OMA techniques to demonstrate the achieved performance gains.

The rest of the paper is organized as follows. Section-2, provides the considered system model, effects of user mobility in NOMA, and problem formulation. In section-3, sum capacity is deeply analyzed under user mobility constraints. The proposed role switching algorithm is discussed in section-4. In section-5, complexity of the proposed technique is analyzed. Detailed simulation results are presented in section-6 to show the achieved performance gains. Finally, the overall work is summarized in section-7.

2. System Model and Problem Formulation

2.1. System Model

Consider two mobile NOMA users; mobile UE$_1$ (MUE_1) and mobile UE$_2$ (MUE_2), with channel gains $|h_1|^2$ and $|h_2|^2$ respectively. MUE_1 is a near user with the strong channel ($|h_1|^2$) and MUE_2 is a far user with the weak channel ($|h_2|^2$), where $|h_1|^2 \geq |h_2|^2$. Channel $|h_i|$ is considered to be independent Rayleigh flat fading with channel coefficient

Table 1
List of symbols.

Symbols	Definition
$\|h_i\|$	Independent Rayleigh flat fading channel
P_t	Total transmit power of BS
γ_t	Total transmit SNR
ρ_i	Power allocation ratio of MUE_i
N_0	Variance of the AWGN
B	Total bandwidth of the system
N	Number of users
d_i	The distance between BS and MUE_i
υ	Path loss exponent
λ_i	Variance for the link between BS and MUE_i
R_i	Data rate of MUE_i
CH_{th}	Predefined channel threshold
ρ_{th}	Predefined power threshold
υt_i	Speed of MUE_i
θ	Direction angle interval
x_i, y_i	Position coordinates of MUE_i
P_i	Current position of MUE_i
SP	Switching position of MUE_i

$h_i \sim CN\ (0, \lambda_i = d_i^{-\upsilon})$ having mean 0 and variance λ_i for the BS − MUE$_i$ link, where d_i is the BS − MUE$_i$ distance, and v is the path loss exponent. For simplicity, single-input and single-output (SISO) antenna configuration is considered. The distances from BS to MUE_1 and MUE_2 are d_1 and d_2 respectively. The PA factors of both users are ρ_1 and ρ_2, where $\rho_1 + \rho_2 = 1$, and $\rho_2 > \rho_1$.

2.2. Effects of Mobility on User Pairing and Power Allocation in NOMA

An illustration of different user mobility scenarios in NOMA is shown in Fig. 1. In what follows, we thoroughly discuss the mobility related issues that severely affect the system performance of NOMA. The goal is to identify the tradeoffs involved when user pairing and power allocation is adopted under user mobility constraints, to achieve high spectral gains in NOMA.

It is observed that the channel condition of a user varies based on its distance from the BS [22]. This affects the user pairing done based on channel condition i.e. a user with good channel paired with a user with worse channel [14]. Conventionally, if users move and change positions such that their channels become too close or the channel ordering reverses, then the BS breaks the pair and makes a new pair with the other users, depending on the channel conditions of both users as shown in Fig. 1(a). However, this breaking and re-pairing could bring high complexity and may result in significant handover failures among pairs.

Consider that a user MUE_1 with strong channel gain is static while MUE_2 with a weaker channel gain is mobile, then the fixed PA affects the sum capacity of the pair due to its varying channel condition. Therefore, a dynamic power allocation technique could be better to enhance the individual as well as pair sum gain than the fixed power allocation [23–26], shown in Fig. 1(b). Furthermore, the sub-channels

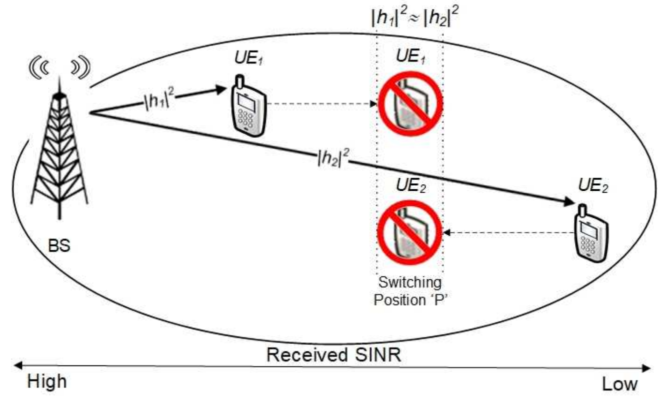


Figure 2: NOMA violation limit at switching position 'P', after which, mobile users roles should be switched.

allocated to the mobile user pairs (UP1, UP2) also need to be updated after the mobile users change the positions as shown in Fig. 1(c). Finally, if MUE_1 and MUE_2 both are considered mobile, then the similar channel gain problem occurs more frequently i.e. when MUE_1 and MUE_2 come very close to each other such that $|h_1|^2 \approx |h_2|^2$. We can overcome this issue by using dynamic power allocation by maintaining the power difference so that the users can easily perform the data recovery.

2.3. Problem Formulation

Based on the analysis above with the defined system model, we have the following problems at hand.

- Firstly, the role switching of MUEs to keep the NOMA system working under mobility when their channel gain ordering is inverted.
- Secondly, the power control to maintain the channel gain difference, when the users are close enough but do not cross.
- Lastly, optimizing their PA factors to maximize pair sum capacity (PSC) of the pair.

The overall optimization problem can be expressed as

$$\max_{\rho_1,\rho_2} \quad (R_1 + R_2) \tag{1a}$$

$$\text{s. t.} \quad \rho_2 \geq \rho_1, \text{if } |h_1|^2 - |h_2|^2 \geq CH_{th} \tag{1b}$$

$$\rho_2 - \rho_1 \geq \rho_{th}, \text{ if } |h_1|^2 - |h_2|^2 \leq CH_{th} \tag{1c}$$

$$\text{where, } \rho_1 + \rho_2 = 1,$$

$$x_{\min} \leq X_P \leq x_{\max}, y_{\min} \leq Y_P \leq y_{\max}. \tag{1d}$$

where R_1, R_2 are the achievable rates, rho_1, rho_2 are the power allocation coefficients and $|h_1|^2$, $|h_2|^2$ are the channel gains of MUE_1 and MUE_2 respectively. The optimization function in (1a) maximizes the PSC, (1b) is the general power allocation rule with distant users, (1c) provides a minimum power difference constraint between users if their channel gains difference is less than a threshold (users close to each other), and (1d) represents the minimum/maximum limits for user mobility.

Note: In this work, the channel threshold CH_{th} value is assumed as a fixed value based on the successful signal recovery of both mobile users and the authors assume that at this CH_{th} value the data recovery at user ends is successful. However, practically determining the channel threshold CH_{th} value is a receiver design problem and it depends on various system parameters and communication channel properties.

3. In Depth Analysis of Mobility in NOMA

In this section, a detailed analysis of sum capacity is performed while considering a downlink NOMA network with mobile users.

3.1. Pair Sum Capacity in NOMA

Consider a near or cell center user (CCU) MUE_1, which is closer to the BS than a far or cell edge user (CEU) MUE_2. BS allocates high power to the CEU with low channel gain and low power to the CCU with high channel gain. Once the PA is done, the BS superimposes both signals and transmits as a single composite signal. As CCU receives more interference from the high powered signal of CEU, SIC is employed at the CCU to recover its desired signal. However, the CEU directly recovers its signal due to low interference from CCU. Considering P_t as the total transmit power of BS, the individual user capacity for MUE_1 and MUE_2 can be calculated as below

$$R_1 = \log_2\left(1 + \frac{\rho_1 P_t |h_1|^2}{N_0}\right) \tag{2}$$

$$R_2 = \log_2\left(1 + \frac{\rho_2 P_t |h_2|^2}{\rho_1 P_t |h_2|^2 + N_0}\right) \tag{3}$$

where N_o represents variance of the additive white Gaussian noise (AWGN). Correspondingly, pair sum capacity (PSC) of the users can be calculated as

$R_{\text{sum}} = R_1 + R_2$

$$= \log_2\left(1 + \frac{\rho_1 P_t |h_1|^2}{N_0}\right) + \log_2\left(1 + \frac{\rho_2 P_t |h_2|^2}{\rho_1 P_t |h_2|^2 + N_0}\right). \tag{4}$$

3.2. Effects of User Mobility on Sum Capacity

In the proposed system, RWP mobility model is considered for user mobility, while BS is fixed at the center of a cellular area. MUEs change their position from point p_o to p_n at each time instant t_s. The position of a MUE$_i$ is uniformly selected within the specified area and its velocity is also selected from the minimum and the maximum velocity interval $[vt_{\min}, vt_{\max}]$. Accordingly, the BS to MUE$_i$ distance d_i is calculated at each new position p_n. A 2D RWP mobility model is considered with distance as a random variable and generalized probability density function (PDF) given as [27]

$$f_d(d) = \sum_{i=1}^{n} \beta_i \frac{d^{\beta_i}}{D^{\beta_i+1}}, \quad 0 \le d \le D, \tag{5}$$

where $n = 3$, $B_i = \left(\frac{1}{73}\right).[324, -420, 96]$, and $\beta_i = [1, 3, 5]$, are the mobility parameters for 2D topology.

To analyze the effect of user mobility on NOMA, a mathematical analysis for ergodic sum capacity of mobile users is provided.

Let, the total transmit SNR γ_t is the ratio of total transmit power P_t and noise N_0 i.e. $\gamma_t = P_t/N_0$. While putting $\alpha_1 = \rho_1 P_t$ in the capacity Eq.2 of MUE_1, it can be written as

$$R_1 = \log_2\left(1 + \gamma_t |h_1|^2 \alpha_1\right). \tag{6}$$

Considering, $S = \gamma_t |h_1|^2 \alpha_1$. The cumulative distribution function (CDF) and PDF of S is given in [15, 28, 29] as below

$$F_S(s) = 1 - e^{-\frac{s}{\lambda_1 \gamma_t \alpha_1}}, \tag{7}$$

$$f_S(s) = \frac{1}{\lambda_1 \gamma_t \alpha_1} e^{-\frac{s}{\lambda_1 \gamma_t \alpha_1}}. \tag{8}$$

Accordingly, the ergodic sum capacity of mobile user MUE_1 can be calculated using the PDF of d and S as

$$R_{1,erg}^{exact} = \int_0^{\infty} \int_0^{D} \log_2(1+s) \frac{1}{\lambda_1 \gamma_t \alpha_1} e^{-\frac{s}{\lambda_1 \gamma_t \alpha_1}} f_d(d) dr ds. \tag{9}$$

By using Eq. (5) and Eq. (8), Eq. (9) can be rewritten as

$$R_{1,erg}^{exact} = -\frac{1}{\ln 2} \text{Ei}(-u) e^u \sum_{i=1}^{n} \beta_i \frac{1}{D^{\beta_i+1}} \times \int_0^{D} d^{\beta_i} dr, \tag{10}$$

where $u = \frac{1}{\lambda_1 \gamma_t \alpha_1}$ and Ei(.) denotes the exponential integral function.

Finally, the simplified expression for the ergodic sum capacity of mobile user MUE_1 is given as

$$R_{1,erg}^{exact} = -\frac{1}{\ln 2} \text{Ei}(-u) e^u \sum_{i=1}^{n} \beta_i \frac{1}{D^{\beta_i+1}} \frac{d^{\beta_i+1}}{\beta_i + 1}, \tag{11}$$

We consider $\alpha_2 = \rho_2 P_t$ where $\rho_2 = 1 - \rho_1$ and calculate the ergodic capacity of MUE_2 as

$$R_2 = \log_2\left(1 + \frac{\gamma_t |h_2|^2 \alpha_2}{\gamma_t |h_2|^2 \alpha_1 + 1}\right). \tag{12}$$

According to [15, 28, 29], the CDF of $Z = \frac{\gamma_t |h_2|^2 \alpha_2}{\gamma_t |h_2|^2 \alpha_1 + 1}$ is given as

$$F_Z(Z) = 1 - e^{-\frac{z}{\lambda_2 \gamma_t (\rho_2 - \rho_1 z)}}. \tag{13}$$

For simplicity Z can be written as $Z = \frac{\rho_2}{\rho_1}$ considering a high SNR approximation $(\gamma_t \longrightarrow \infty)$. Then, the ergodic capacity of MUE_2 becomes

$$R^{approx}_{2,erg} = \log_2 \left(1 + \frac{\alpha_2}{\alpha_1}\right). \tag{14}$$

Therefore, the ergodic sum capacity of the mobile users pair can be calculated as

$$R_{sum,erg} = R^{exact}_{1,erg} + R^{approx}_{2,erg}. \tag{15}$$

On the basis of analysis above, the individual capacity graphs of both near and far mobile users are shown in the Fig. 3(a) and Fig. 3(b), according to their positions and distances from the BS without the role switching technique. The result shows that without role switching a near mobile user (MUE_1) cross a far mobile user (MUE_2) more than once while its data rate drastically decreases much less than the data rate of a far mobile user (MUE_2). Furthermore, at the position P=100, its data rate drops even below 1 bps. Thereby, the sum capacity of the overall NOMA system is minimized. Hence, it supports our defined problem statement above in subsection-2.3.

4. Role Switching and Power Optimization

The proposed work address the NPVP in NOMA under user mobility by considering the variable channel gains of users that serve as a baseline of NOMA pairing. In order to show the working principle of the proposed scheme, consider that the two MUEs (MUE_1, MUE_2), following RWP mobility model, come very close or even cross each other multiple times. Every time the MUEs come very close to each other, their channel conditions at the switching position P become approximately similar. Conventional NOMA PA schemes that focus on sum capacity maximization may assign very close PA factors to both users, without caring about the data recovery problems at the user ends. Moreover, if the users cross each other, then their roles as near/far users and the associated PA ordering both need to be switched. In situations when users come very close i.e. $|h_1|^2 - |h_2|^2 \leq CH_{th}$ to each other, the OPRS-NOMA scheme ensures the power difference between paired users to be greater than a predefined power threshold ρ_{th}, i.e.,

$$\rho_2 - \rho_1 \geq \rho_{th}. \tag{16}$$

Conventionally, PA of the users should not be equal, ρ_1 should be smaller than 0.5, and ρ_2 larger than 0.5. When both users are close to each other, and CEU has small target rate, then in order to maximize PSC, BS can allocate $\rho_1 = 0.49$ and $\rho_2 = 0.51$, as giving maximum allowed power to CCU improves the PSC. This is similar to bisection search power optimization (BSPO [2]). However, such close PA factors of the two users can significantly degrade their data recovery process; a predefined threshold based PA can resolve the issue.

Algorithm 1 **O**ptimized **P**ower **R**ole **S**witching (OPRS-NOMA)

Input:
Speed interval: $vt_{\min}$ to $vt_{\max}$.
X and Y position interval: $(x_{\min}, y_{\min})$ to $(x_{\max}, y_{\max})$.
Direction angle interval(θ): $-\pi$ to π.
Number of users: N.
Distance between BS and MUE$_i$ ($D_{\text{BS}-\text{MUE}_i}$): $1 \times N$.
Output:
R_1 and R_2
Notation: Subscripts 1 and 2 represents near and far users respectively.
Initialization:
Channel difference threshold CH_{th}.
Power difference threshold ρ_{th}.

Generate RWP mobility (Input)
    {**return** position P}
for each position P of MUE*s*
    Calculate Distances: $D_{\text{BS}-\text{MUE}}$
    Compute channel matrix **H** from $D_{\text{BS}-\text{MUE}}$
    Calculate channel gains: $|h_1|^2, |h_2|^2$
    if $|h_1|^2 > |h_2|^2$ **AND** $|h_1|^2 - |h_2|^2 > CH_{th}$ **then**
        Apply BSPO without power threshold ρ_{th}
        {**return** (ρ_1, ρ_2)}
    else if $|h_1|^2 > |h_2|^2$ **AND** $|h_1|^2 - |h_2|^2 \leq CH_{th}$ **then**
        Apply BSPO with power threshold ρ_{th}
        {**return** (ρ_1, ρ_2)}
    else if $|h_1|^2 < |h_2|^2$ **AND** $|h_2|^2 - |h_1|^2 \leq CH_{th}$ **then**
        Apply Role Switching ▷ users ordering switched
        Apply BSPO with power threshold ρ_{th}
        {**return** (ρ_1, ρ_2)}
    else ▷ $|h_1|^2 < |h_2|^2$ **AND** $|h_2|^2 - |h_1|^2 > CH_{th}$
        Apply Role Switching ▷ users ordering switched
        Apply BSPO without power threshold ρ_{th}
        {**return** (ρ_1, ρ_2)}
    end if
    Calculate eq. (2) and eq. (3)
end for

4.1. Effects of OPRS-NOMA Algorithm

The proposed OPRS-NOMA works by checking the channel conditions of the paired users at each new location p_n. In case their channel gain ordering is the same as previous, the algorithm only focuses on the power optimization part; BSPO or BSPO with threshold. However, if the channel gain ordering of the users change, then the algorithm changes their roles as near/far users (and inverts their power order) followed by power optimization using BSPO or BSPO with threshold. This can be noticed in the if-else conditions in Algorithm 1, which are based on the channel gains of paired users. Further details of the OPRS-NOMA algorithm are given in the subsections below.

4.1.1. CASE-I (when, $|h_1|^2 > |h_2|^2$)

In order to understand the proposed OPRS-NOMA algorithm, lets consider a pair of two mobile users; MUE_1 and MUE_2 with channel gains $|h_1|^2$ and $|h_2|^2$ respectively. The channel gain varies, if a mobile user moves towards or away from the BS. However, sometimes during mobility channel gain order ($|h_1|^2 > |h_2|^2$) remains the same even both users are closer to each other. Therefore, dealing with channel gain variations and ordering along with the power control technique is the vital part of the OPRS-NOMA algorithm.

In the OPRS-NOMA algorithm, the distance as well as channel matrix $\mathbf{H}$ is updated at each position P of the MUEs. The first two conditions refer to the case where channel ordering of the paired mobile users (MUE_1, MUE_2) does not change, and therefore no role switching is needed. The difference between these two conditions is whether the channel gain difference of MUEs is larger or smaller than a threshold CH_{th} i.e., the MUEs are far away from each other or closer.

In the given conditions, the large channel gain difference corresponds to BSPO without power threshold ρ_{th} because the channel gains of both MUEs are enough to easily perform the data recovery. Therefore, only BSPO is used to optimize the powers in order to maximize the sum capacity. Otherwise, BSPO with power threshold ρ_{th} is used to maintain the power difference for the users closer enough to each other because their channel gain difference is less than the predefined threshold CH_{th}. Thereby, maintaining the overall channel gain awareness during mobility overcomes the NPVP.

4.1.2. CASE-II (when, $|h_1|^2 \leq |h_2|^2$)

Contrary to the above scenarios, if the mobile users cross each other at position P then, the channel gain ordering is inverted, which causes the NPVP. That is why a mobility aware role switching with optimal PA is required instead of breaking and re-making new pairs which may cause severe handover failures and can significantly affect the network performance. In the OPRS-NOMA, the other two conditions refer to the case where channel ordering of the users changes (near and far users cross each other), which requires both role switching and PA. The difference between both these conditions is also in terms of the channel gain difference. Both conditions refer to the case where users ordering change and their roles and PA need to be switched. In case the channel gains are still close to each other (just after crossing each other), then role switching and BSPO with threshold is used. Otherwise, role switching with conventional BSPO is used.

This investigation, strengthens the following points:

- Firstly, the OPRS-NOMA overcomes the NPVP of conventional NOMA by checking the channel condition of both users, which should be greater then the predefined channel threshold CH_{th}.
- Secondly, the minimum power threshold ρ_{th} condition is also checked if the channel gains are less than channel threshold CH_{th}.
- Finally, the OPRS-NOMA switches the roles and performs power optimization if required on the basis of channel difference by using the conventional BSPO technique discussed in [16].

5. Complexity Analysis

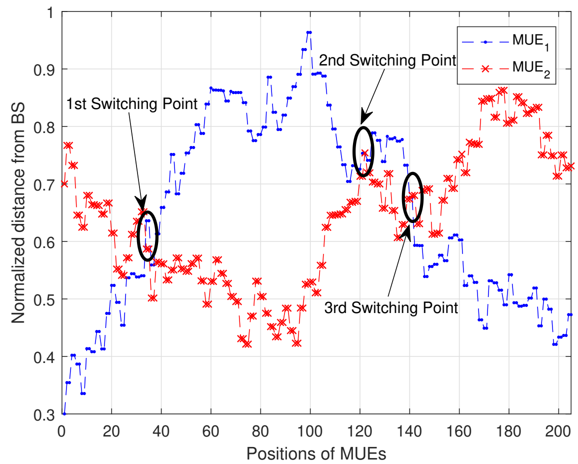
For the complexity analysis, the proposed OPRS-NOMA is compared with the conventional NOMA without role switching. The computational complexity of an optimal user pairing technique based on conventional NOMA is very high as it requires an exhaustive search among all the users [30]. While, in the proposed OPRS-NOMA, there is only switching of the near/far roles for already paired users. Lets denote the complexity of role switching as a constant cost for every single iteration i.e., $\mathcal{O}(1)$ because it only needs to switch the roles as near/far of already paired users. Additionally, it is known that the complexity of selecting an optimal user for pairing from a search space of K-users is $\mathcal{O}(K)$. Suppose, during the n_{th} iteration, there is a switching point where a conventional NOMA technique breaks a previous pair and makes a new pair while the proposed OPRS-NOMA technique switches roles as near/far users by switching the associated PA ordering. Then, the computational complexity of OPRS-NOMA with role switching and conventional NOMA without role switching during this n_{th} iteration will be $\mathcal{O}(1)$ and $\mathcal{O}(K)$ respectively and if there are total N iterations the complexity will become $\mathcal{O}(N)$ and $\mathcal{O}(NK)$ respectively. Furthermore, the complexity of BSPO is given as $\mathcal{O}(-\log \epsilon)$, where ϵ is the search precision [31]. Hence, the overall complexity of the OPRS-NOMA is less than conventional NOMA.

6. Simulation Results and Discussion

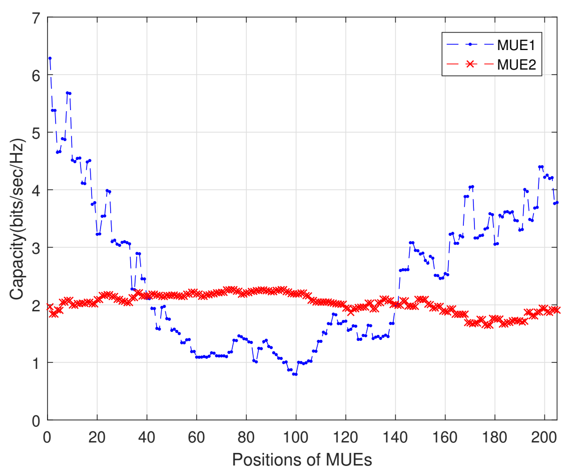
Consider two MUEs (MUE_1, MUE_2) following RWP model in a downlink NOMA system that change their positions, speed and direction at each time instant t_s. Rest of the

Table 2
Summarized table of the important simulation parameters.

Basic Simulation Parameters	
Channel Type	Rayleigh Flat Fading
Cell Radius	Normalized to 1
BS Transmit Power	Normalized to 1
Transmit SNR Range	5 dB to 40 dB
Bandwidth	1 Hz
Transmission Mode	Single Input Single Output
Mobility Model	RWP Model

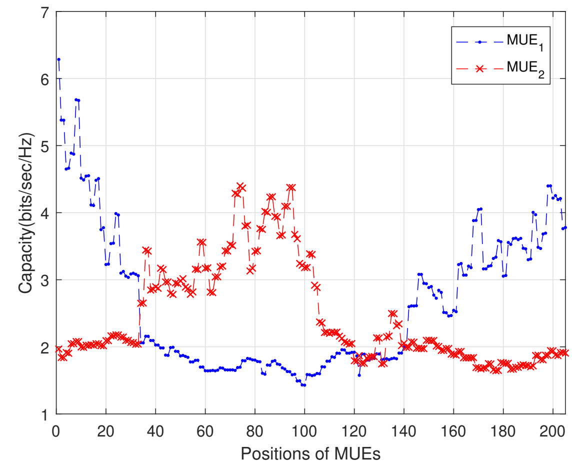


(a) Normalized distance of MUE_1 and MUE_2 from the BS and the switching points where the roles should be switched.

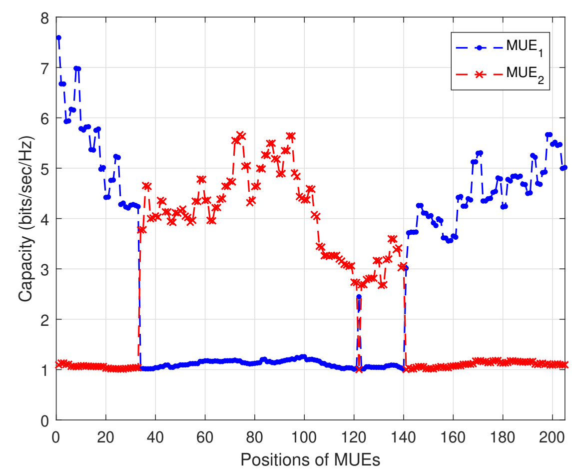


(b) Individual capacity of MUE_1 and MUE_2 in conventional NOMA under RWP mobility model without switching.

Figure 3: RWP based mobility illustration of MUE_1, MUE_2, and their corresponding capacity results without role switching.



(a) MUE_1, MUE_2 individual capacity; role switching with fixed power allocation.



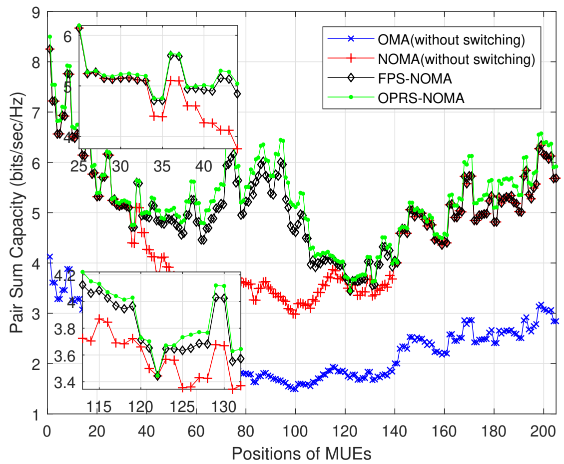
(b) MUE_1, MUE_2 individual capacity; role switching with optimal power allocation.

Figure 4: Comparison of fixed power role switching and optimized power role switching.

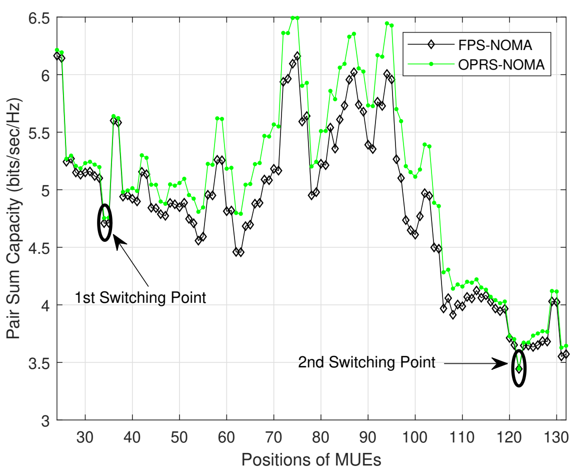
parameters are set as target rate $T_R = 1$ bit/s/Hz, bandwidth $B = 1$ Hz, signal-to-noise ratio SNR = 5−40dB, and the BS to MUEs distances normalized to 1. Simulation parameters are summarized in the Table. 2 Performance is evaluated in terms of individual and sum capacity (PSC) of paired users.

In Fig. 3(a)., normalized BS to MUEs distances are shown at different time instant t_s, and the 1st switching point at P = 34 is shown, where the channel condition of the MUE_1 becomes worse than the MUE_2 thereby violating the NOMA principle. The far end mobile user MUE_2 after crossing the near mobile user MUE_1 at 1st switching point remains as CEU at BS that uses the conventional NOMA schemes without role switching. By contrast, a BS using the proposed role switching scheme based on the channel conditions switches the roles of mobile users as near and far. Further, mobile users cross twice more but at the 3rd switching point, the mobile users after crossing perform like a normal near and far user. Additionally, individual user capacity is shown in Fig. 3(b). at positions or distances from the BS shown in Fig. 3(a). It can be seen that the most critical part is from position 40 to 140, where MUE_1 performs relatively lower than the MUE_2 even it is considered as a CCU. Also, the capacity of MUE_1 at position 100 is lower than the target rate i.e., 1 bps. Moreover, without role switching, the capacity of MUE_2 is still not increased as its channel condition becomes better than MUE_1.

The individual user capacity results are shown in Fig. 4a. after applying role switching with fixed power to show the benefits. A significant capacity gain of near and far users can be noticed after roles are switched. Especially, the capacity of a far end user MUE_2 (previously with weak channel gain) becomes better than MUE_1 after applying role switching technique because it is now considered as a near user by the BS. Therefore, the individual user capacity of near and



(a) PSC gain before and after switching with fixed and optimized power in NOMA system.



(b) PSC gain of the OPRS-NOMA in the interval between two switching points.

Figure 5: Detailed comparison in terms of PSC of the proposed OPRS-NOMA technique with OMA and conventional NOMA without switching.

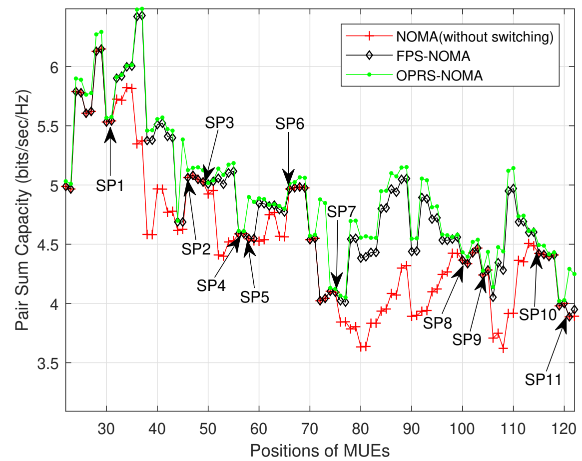


Figure 6: Comparison of the proposed OPRS-NOMA with the FPS-NOMA and conventional NOMA in terms of PSC when mobile users switch roles multiple times.

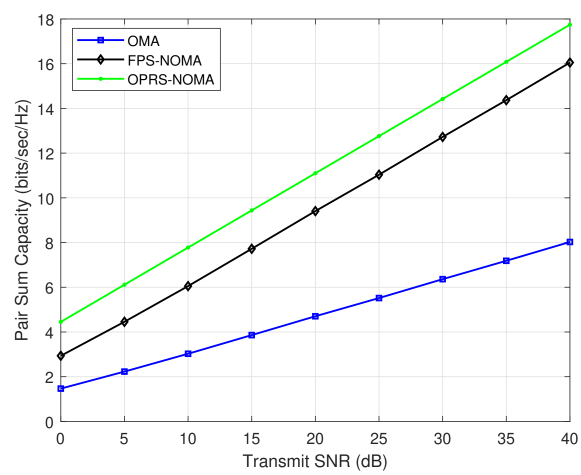


Figure 7: Comparison of the proposed OPRS-NOMA, FPS-NOMA, and OMA with different transmit SNR values at a switching point 'SP_i' where roles are switched.

far users after applying role switching technique is increased due to allocating the appropriate powers according to their channel gains. Furthermore, to enhance the pair sum capacity, the BSPO technique is used which further maximizes the capacity of the near user by allocating optimal power to the far user, after achieving the target rate as shown in Fig. 4(b).

To show the advantage of NOMA when the users are mobile, the performance of the proposed OPRS-NOMA is compared with conventional NOMA with fixed power switching (FPS-NOMA) and conventional OMA and NOMA with no role switching. Switching positions can be seen in Fig. 5(a). to show the pre/post role switching gain. Again, it can be observed in Fig. 5. that how role switching technique avoids NPVP by continuously switching the roles where both mobile users cross each other. All things considered, the capacity gain of the proposed OPRS-NOMA is clear and more than the other compared techniques. This much capacity gain strengthens the importance of the proposed OPRS-NOMA. Additionally, the comparison of PSC gains achieved by the OPRS-NOMA and FPS-NOMA between the two switching positions is shown in Fig. 5(b). Between two switching points, the capacity gain of OPRS-NOMA is clear and more than the FPS-NOMA because the OPRS-NOMA further enhance the capacity by allocating the optimal powers to both users based on their target rates.

Furthermore, to show the significant gains of OPRS-NOMA as compare to the FPS-NOMA and NOMA without switching, the random behavior of mobile users with multiple times role switching is presented in Fig. 6. The capacity gains between switching positions can be seen where role switching technique performs better far better than the NOMA without switching. Here, we want to highlight the superiority of the role switching technique in comparison with conventional NOMA without role switching, where a BS repeatedly breaks and pairs users at those switching points which results in high complexity. While, the proposed OPRS-NOMA switches the role as near and far without breaking and pairing it again.

Finally, Fig. 7. is presented to show the impact of different transmit SNR on the performance of the proposed OPRS-NOMA. Further, it is shown that the OPRS-NOMA still performs better by varying the transmit SNR at the BS. It can be seen in Fig. 7. that the capacity with role switching is higher than OMA, either with fixed power (FPS-NOMA) or optimized power (OPRS-NOMA) because role switching efficiently maintains the power allocations of the mobile users with strong and weak channel gains during the user mobility. Further, the difference between the gains of the OPRS-NOMA and OMA increases with the increase of the transmit SNR at the BS. The gain is linear because the performance is evaluated with different SNR values at a single switching point 'SP_i' where the roles are switched. Thus, showing the best performance of the proposed OPRS-NOMA for user mobility.

7. Conclusions

In this paper, a role switching and power allocation technique, OPRS-NOMA, is proposed for mobile users under the RWP mobility model in NOMA. OPRS-NOMA overcomes the NPVP problem of mobile NOMA users by switching the roles based on their channel gains when they come very close or cross each other. Power allocation is also updated based on the locations of mobile users. As for performance measures, per-user capacity and pair sum capacity are obtained by simulations. It can be seen that the proposed OPRS-NOMA outperforms the conventional NOMA and OMA with and without role switching. Conclusively, analyzing the impact of user mobility is essential for network performance. Although, investigating the users' speeds on the frequency of role switching is very important, and a detailed analysis of this is subject to our future works. Furthermore, the performance gain analysis in terms of capacity and BER for reliable data transmission will be discussed in detail in the future. Moreover, addressing user pairing problems and power allocation issues for multiple mobile users in NOMA are some interesting future research directions.

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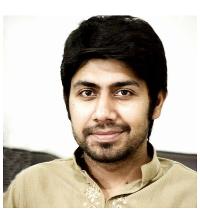

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