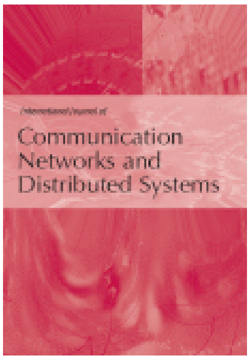

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Effect of user mobility under Rician fading on power allocation for non-orthogonal multiple access strategy

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Abstract: Non-orthogonal multiple access (NOMA) has been envisaged as a promising technique to meet the demand for massive machine-type communication (mMTC) devices. However, designing a NOMA system required a proper comprehensive study of user mobility, user switching, and imperfect successive interference cancellation (Im-SIC). In this paper, the effect of user mobility and Rician fading channel on power allocation for non-orthogonal multiple access (PA-NOMA) strategy is thoroughly investigated. This paper also discusses the challenges faced during the power allocation to multiple NOMA users. Mobility of the users violates the basic channel gain conditions of the NOMA users, therefore, to maintain the fairness index of the individual cell edge users, dynamic power allocation strategy is adopted. Simulation results show that user mobility and Im-SIC have a significant effect on the PA-NOMA strategy for multiple users in terms of sum-rate capacity, average bit error rate, and fairness index.

Keywords: fairness index; PA-NOMA; imperfect SIC; Rician fading; user mobility; user switching.

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1 Introduction

With the tremendous increase in internet of things (IoTs) devices, it has been a tremendous challenge for telecommunication industry to meet the increasing demand of high availability as well as high spectrum utilisation (Lin et al., 2020; Dai et al., 2015; Liu et al., 2021; Dai et al., 2018). Conventionally (Akbar et al., 2021; Tao et al., 2015; Ghafoor et al., 2022) various orthogonal multiple access techniques have been successfully implemented to the existing wireless network. In orthogonal multiple access, data transmission from the multiple users is achieved by assigning subsets of time-frequency resources to different users. But these are insufficient to address the increasing demand for high data rates and high spectral efficiency out of the limited availability of radio spectrum (Verma and Sahu, 2018; Shi et al., 2020; Kumar and Kumar, 2020). To overcome these issues, non-orthogonal multiple access (NOMA) is a prominent technique to achieve high throughput and supporting a large number of users (Sreya et al., 2021; Tsai and Wei, 2018). The basic idea of NOMA is to serve multiple users over the same radio frequency resource block (Lee and Cho, 2018). The various NOMA techniques have been proposed on how to realise NOMA such as power-domain NOMA, interleave division multiple access (IDMA), or sparse code multiple access (SCMA) (Akbar et al., 2021; Keating et al., 2018). In power-domain NOMA, users are allocated different power levels according to their channel characteristics and location w.r.t. the base station (BS) (Ismail et al., 2020). In IDMA (Kucur et al., 2018), multiple users are assigned different interleaving pattern in the transmit sequence and receiver use this pattern to decode. In SCMA, each user information is conveyed using a unique spreading code according to the spreading matrix (Wu et al., 2018; Liu and Yang, 2021; Deka et al., 2021). With the evolution of 5G techniques, NOMA is adopted to increase the spectral efficiency and maximising the sum-rate capacity of the system. NOMA can be adaptively configured to satisfy the diverse services and applications which make it suitable to be used for future 5G networks and beyond (Kader et al., 2017; Wang et al., 2016). The general framework for the different NOMA schemes, application requirements, prototype, and future research directions are specified in 3rd generation partnership project (3GPP) standard (Ghafoor et al., 2022; Makki et al., 2019). Wan et al. (2019) have proposed a novel NOMA operation unit to accommodate an arbitrary number of users by integrating NOMA with orthogonal resource allocation strategy. They have also incorporated the index modulation technique to improve the data services for edge users. The authors have proposed a unified model for the comprehensive literature survey on implementation aspects and related open issues of NOMA system (Kucur et al., 2018). They have also included multiple-input multiple-output (MIMO) and cooperative communication scenarios for the detailed analysis. A low complexity suboptimal power allocation technique was proposed to maximise the ergodic capacity of MIMO-NOMA system (Sun et al., 2015). Ahmed et al. (2020) considered the multi-user over Rayleigh fading channel and successive interference cancellation (SIC) to analyse the performance of NOMA system. At each terminal, probability density function of signal to interference plus noise ratio (SNIR) is exploited to obtain the outage probability bit error rate. A stochastic geometry approach is proposed to analyse the outage probability and achievable data rates for the downlink and uplink NOMA system in a dense wireless network (Zhang et al., 2017). Kara and Kaya (2018) derived an exact closed-form bit error rate expression under Rayleigh fading channel and SIC process for the downlink system. The derived expressions are validated through simulation to analyse the effect of power allocation on downlink (DL)-NOMA. The impact of BS transmit power level and power control strategies of the user on the D2D connection for two user NOMA system is investigated in Madani and Sodagari (2018). The optimised power allocation coefficients are determined for different modulation schemes for near and far users to analyse the performance of DL-NOMA system in presence of SIC error over the Rayleigh fading channel (Jain et al., 2020; Niharika, 2018). The issues of decoding order mismatch with the user index in cancellation sequence of NOMA with imperfect SIC is addressed in Manglayev et al. (2017a). Ding et al. (2014) investigated the ergodic sum rate and outage performance of NOMA in a downlink scenario with random deployment of users. They found that when the user's rate and power coefficients are carefully chosen, NOMA users can achieve better outage performance compare to the conventional orthogonal multiple access techniques. Azam et al. (2020) proposed an optimised power role switching non-orthogonal multiple access (OPRS-NOMA) for mobile users under a random waypoint mobility model. Based on channel gain conditions, role of near cell users and far cell users are interchanged. Furthermore, a bisection power optimisation technique is applied to maximise the average sum-rate capacity. Some of the main drawbacks if the user mobility is not taken into consideration while designing the NOMA communication systems especially for the downlink scenario is presented (Masaracchia et al., 2020). Narottama and Shin (2019) proposed a dynamic power allocation (DPA) strategy to maximise the sum-rate capacity of the overall system. In doing so, authors have considered the perfect SIC constraints and while ignoring the issues of multiple users switching. In case of mobile environment, suitability of DPA is more than FPA for PD-NOMA system is highlighted in Mounir et al. (2022). However, to the best of our knowledge, most of the work in power allocation ignores the Im-SIC, user mobility, and user switching conditions for the practical applications of PD-NOMA. Although, having increased in the complexity of the system, yet the real-time parameters need to be considered for the practical scenario. In this paper, the DPA and fixed power allocation (FPA) strategies are considered to discuss the effect of user mobility under Rician fading channel on the sum-rate capacity, bit error rate, and fairness index of the system. The key contributions of this paper can be summarised as:

- Constraints such as Im-SIC, transmit power coefficient, fairness index, etc. are presented for DPA-NOMA and FPA-NOMA systems.
- Simulation of DPA-NOMA and FPA-NOMA under user mobility and user switching is performed to analyse the performance in terms of sum-rate capacity, fairness index, and bit error rate.

The rest of the paper is organised as follows: Section 2 defines the system model and problem formulation. Section 3 derives the simulation results for DPA-NOMA and FPA-NOMA strategy under perfect and Im-SIC constraints. Section 4 provides the conclusions of the paper.

2 System model and problem formulation

Let us consider a downlink system in which BS transmitted a superposition signal to all the N NOMA users (Dai et al., 2015; Lee and Jung, 2020). Each users decode its own signal considering signal of other lower power coefficient users as interference or noise using SIC process. However, user with the highest power coefficient will decode it signal directly without performing SIC process. The superposition signals of N NOMA users transmitted from the BS can be written as:

$$x = \sum_{i=1}^{N} x_i * \sqrt{\alpha_i} * P_t \tag{1}$$

where x_i is the information of i^{th} user, P_t is the total transmitted power of the BS and α_i is the power allocation coefficient to i^{th} user. The received signal at the k^{th} users can be expressed as:

$$y_k = h_k * \sum_{i=1}^{N} x_i(t) * \sqrt{\alpha_i} * P_t + N_o \tag{2}$$

Without the loss of generality, channel gains are assumed to be ordered as $|h_1|^2 \leq |h_2|^2 \leq \ldots \leq |h_N|^2$ where h_k is channel coefficient of the k^{th} user and N_o is the additive white gaussian noise (AWGN) power (Thapliyal et al., 2022). Channel gain conditions are considered as an independent and identical distribution Rician fading with mean μ and variance σ^2, which simplifies to Rayleigh fading when $\mu = 0$. At each user, the SIC process is used to decode the instantaneous signal to interference and noise ratio (SINR). For k^{th} user, where $k \in [1, N]$, the SINR can be expressed as follows:

$$R_k = \log_2\left(1 + \frac{\alpha_k |h_k|^2}{\sum_{i=k+1}^{N} \alpha_i |h_i|^2 + N_o}\right) \tag{3}$$

Then the SINR of 1st user can be expressed as:

$$R_1 = \log_2\left(1 + \frac{\alpha_1 |h_1|^2}{\sum_{i=2}^{N} \alpha_i |h_i|^2 + N_o}\right) \tag{4}$$

However, this is the case when there is perfect SIC. In case of Im-SIC, there will be residue of previously decoded users, i.e., from 1 to k users which caused interference leads to the problem of SIC errors. Considering the residues of previously decoded users due to SIC errors, the SINR for k^{th} user can be expressed as follows:

$$R_k = \log_2\left(1+\frac{\alpha_k |h_k|^2}{\sum_{i=k+1}^{N}\alpha_i |h_i|^2 + \sum_{i=1}^{k-1}\varepsilon * \alpha_i |h_i|^2 + N_o}\right) \tag{5}$$

where ε is the fraction of residue of previously decoded users left due to Im-SIC error assuming that decoding order will remain the same. When ε is zero, it means there is no residue of previously decoded users, i.e., signal is perfectly decoded or in simple words, when SIC is perfect.

2.1 Problem formulation

An overall goal of the problem is to maximise the sum-rate capacity under user mobility. For doing so, the power allocation coefficient should be carefully chosen as well as satisfy the minimum transmission rate for the far/edge user. Mathematically, it can be expressed as:

$$Max\left(\sum_{i=1}^{N} R_N\right) \tag{6}$$

$$\text{w.r.t. } \alpha_1 + \alpha_2 + \alpha_3 + \ldots + \alpha_N = 1 \tag{6.1}$$

$$\alpha_1 \geq \alpha_2 \geq \alpha_3 \geq \ldots \geq \alpha_N \tag{6.2}$$

$$\alpha_N > \left((2^R - 1)\sum_{i=1}^{N-1}\alpha_i\right) \tag{6.3}$$

here R is the minimum transmission rate for the far/edge user. α_k is the power allocation coefficient for k^{th} users such that sum of power allocation coefficient is equal to one. For simplicity, power allocation coefficients are arranged in decreasing order according to the constraint (6.2). Constraint (6.3) maintains the fairness among the users. Fairness index helps us to determine how fair the system capacity is distributed among the adjacent users is calculated using the equation given below (Manglayev et al., 2017b; Salehi et al., 2020):

$$F_{\min} = \frac{\left(\sum_{i=1}^{N} R_i\right)^2}{N * \left(\sum_{i=1}^{N} R_i^2\right)} \tag{7}$$

Fairness index can be ensured by controlling the power allocation among the adjacent users. Initially (Ding et al., 2014; Althunibat et al., 2019) users are distributed randomly around the BS within the cell radius (D). The initial position of a user equipment (UE_n) at time instant t = 0 is taken as [$X_{UE,N,0}$, $Y_{UE,N,0}$] with BS at [0, 0]. The next positions or coordinates of the UE_n are calculated using the previous position with the help of the expression given below:

$$X_{UE,N,t+1} = X_{UE,N,t} + d_{BS-UE,N,t,t+1} * \cos\left(\theta_{N,t,t+1}\right) \quad (8)$$

$$Y_{UE,N,t+1} = Y_{UE,N,t} + d_{BS-UE,N,t,t+1} * \sin\left(\theta_{N,t,t+1}\right) \quad (9)$$

where ($X_{UE,N,t}$, $Y_{UE,N,t}$) donates the previous position of the user *n* at time *t* and $d_{UE,N,t,t+1}$ is the Euclidean distance between new position at time instant *t* + 1 and previous position at time instant *t* (Narottama and Shin, 2019). Euclidean distance method is used to determine the distance between the present and previous position of the user. Algorithm 1 shows the user mobility strategies followed to perform the simulation.

Algorithm 1 User mobility strategy

Input: Consider the *N* users. Initial position of UE_n is ($X_{UE,N,0}$, $Y_{UE,N,0}$) at time instant *t*.

Uniform speed: [$S_{n\_\min}$, $S_{n\_\max}$]

Direction angle: [$\theta_{n\_\min}$, $\theta_{n\_\max}$]

Distance between *BS* and UE_N at time instant (*t*) is calculated using Euclidean distance formula:

$$d_{BS-UE,N,t} = \sqrt{(X_{BS} - X_{UE,N,t})^2 + (Y_{BS} - Y_{UE,N,t})^2}$$

Next coordinates of the UE_N at time instant (*t* + 1) is computed $d_{UE,N,t+1}$ using equations (8) and (9).

The channel gain characteristic varies with the change in positions of the users w.r.t. BS (Aalo et al., 2016; Yin et al., 2019). User position plays an important role in attaining the good channel conditions. So, it is necessary to have the information of current channel gain conditions of the user w.r.t. the user position. In addition to this, to fulfil the requirements of NOMA system, we allocate more power to far users and less power to near users (i.e., users with the worst channel gain coefficients shall get the higher power fraction) (Yang et al., 2017; Mouni et al., 2021). For the conventional FPA-NOMA system, power allocation coefficients are fixed throughout the simulation. Whereas in DPA-NOMA system, selections of power allocation coefficient are dynamic and satisfy the constraints of equation (6). While allocating transmitting power to the users, the change in position of the near and far user (i.e., user switching condition) is also taken into consideration. User switching condition means that the near user became the far user and the far user became the near user. Algorithm 2 defines the procedure for computing the sum-rate capacity, bit error rate, and fairness index for FPA-NOMA and DPA-NOMA respectively.

Algorithm 2 Procedure for computing the fixed and dynamic power allocated coefficient, sum-rate capacity, bit error rate and fairness index

Input: Random generation of next positions of the individual users UE_1, UE_2, …, UE_N and calculate the distance between *BS* and UE_N ($d_{BS-UE,N,t}$). The total simulated user positions derived from equations (8) and (9) are denoted by the time instant (t_m = 26 where *m* = 1, 2, 3, …, 26).

Initialisation: For simplicity, assuming only 2 users. Transmitted power (P_t = 0:2:50 dBm).

For FPA-NOMA, power allocation coefficients are fixed (i.e., 0.75 and 0.25).

For DPA-NOMA, compute the dynamic power allocation coefficient (DPA) for (t_m) time instants user locations.

Calculate $d_{BS-UE,N,t}$ for each user

If $d_{BS-UE,1,t} > d_{BS-UE,2,t}$ **then**

More power allocated coefficient (i.e., $\alpha_1 > \alpha_2$) will be allocated to 1st user

Else if $d_{BS-UE,1,t} < d_{BS-UE,2,t}$ **then**

More power allocated coefficient (i.e., $\alpha_2 > \alpha_1$) will be allocated to 2nd user

End if

Calculate capacity for 1st user and 2nd user.

For Transmitted power (P_t = 46 dBm).

For t in user (t = 1) positions

For N in user equipment (UE_N = 2)

Compare the average individual sum-rate capacity, average bit error rate and fairness index for analyse the impact of Im-SIC on the system.

End for

End for

End for

End for

End for

3 Simulation results

For simplicity, it is considered that the users UE_1 and UE_2 are moving with uniform speed and in any direction w.r.t. BS within the cell radius of 100 m. Unless other stated, the simulation parameters are defined in Table 1.

Table 1 Simulation parameters

Parameter	*Value*
Bandwidth	20 MHz
Carrier frequency	1 GHz
Channel model	Rician fading
Cell radius	100 m
Path loss exponent	4
Noise power spectral density (N_o)	–174 dBm/Hz
Transmit power (P_t)	0:2:50 dBm
Message length (packets)	1e5
Epsilon (ε)	10^{-4}

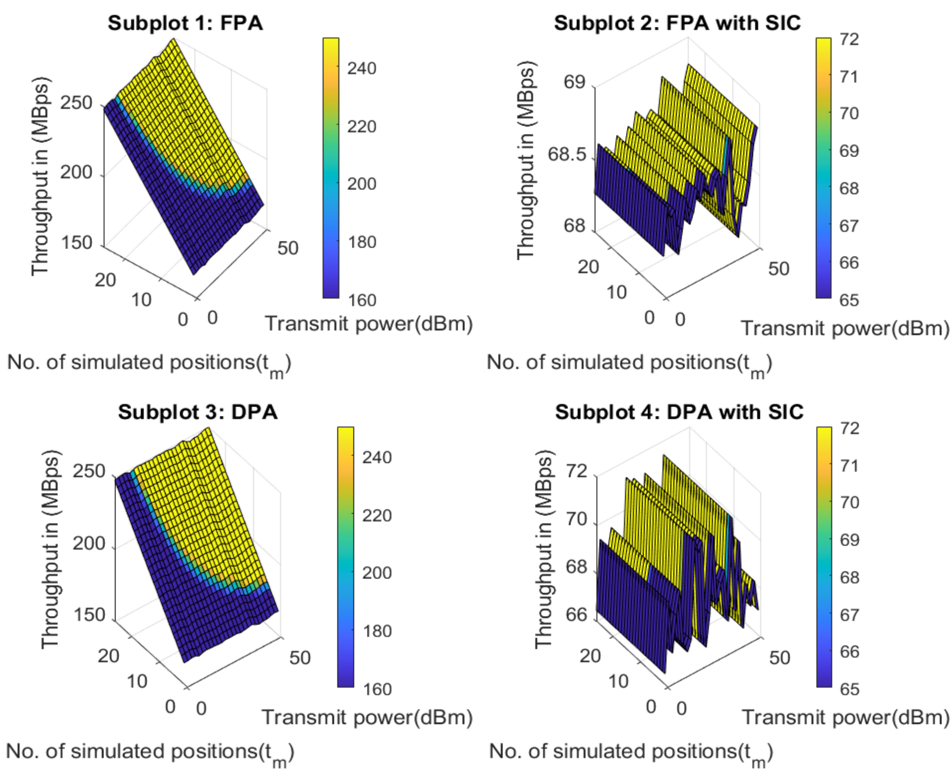
For conventional FPA-NOMA system, we have taken fixed power allocation coefficient as [0.75 0.25]. However, in case of DPA-NOMA system, DPA coefficients are selected dynamically such that they will satisfy equations (6.1), (6.2) and (6.3) constraints of equation (6). The computed DPA-NOMA power allocation coefficients are given below:

$$\begin{bmatrix} PA_1 \\ PA_2 \end{bmatrix}_{2\times 26} = \begin{bmatrix} 0.0204 & 0.6770 & \dots & 0.0403 \\ 0.9796 & 0.3230 & \dots & 0.9597 \end{bmatrix} \quad (10)$$

The overall system capacity or throughput for the range of transmit power (0:2:50 dBm) and different simulated user positions denoted by time instants (t_m, where m = 1, 2, 3, …, 26) are inspected to analyse the impact of FPA-NOMA and DPA-NOMA under perfect and Im-SIC constraint as shown in Figure 1. For both FPA-NOMA and DPA-NOMA system, the overall throughput is achieved at user position (t_{19}) having user-1 coordinates (–44.6752, 77.0747) and user-2 coordinates (32.6551, –68.8018) respectively. With the increase in transmit power, the overall system throughput increased for both FPA-NOMA and DPA-NOMA. For perfect SIC, the highest throughput achieved is nearly same as 250 Mbps for FPA-NOMA and DPA-NOMA whereas for Im-SIC, the highest throughput achieved is 68.831 Mbps and 71.426 Mbps for FPA-NOMA and DPA-NOMA respectively. The user locations w.r.t. to BS derived by equations (8) and (9) are given below:

$$\begin{bmatrix} d_{BS-UE,1,t} \\ d_{BS-UE,2,t} \end{bmatrix}_{2\times 26} = \begin{bmatrix} 66.0299 & 74.1392 & \dots & 73.7705 \\ 16.1016 & 65.9790 & \dots & 28.6522 \end{bmatrix} \quad (11)$$

Figure 1 Shows the overall throughput v/s the transmit power and no. of simulated positions with perfect or Im-SIC constraint (see online version for colours)



During the entire simulation, there are 12 times user switching takes place. Figure 2 shows the variation of user distance w.r.t. BS v/s the no. of simulated positions. For user-1 and user-2, multiple times users are switched between the near user and far user. Due to these users switching, there is frequent variation in power allocation coefficient among the users which impacts the individual performance of the user. In addition to this, the impact of Im-SIC is on the near user as it performs a decoding process for its data. Even for a small ε value, i.e., 10^{-4} of error propagation, there is a significant impact on the average sum-rate capacity of the users. Figure 3 shows the overall throughput of FPA-NOMA and DPA-NOMA with and/or without Im-SIC constraint for user-1 and user-2 respectively.

Figure 2 Shows the variation of user distance w.r.t. BS v/s no. of simulated positions (t_m) (see online version for colours)

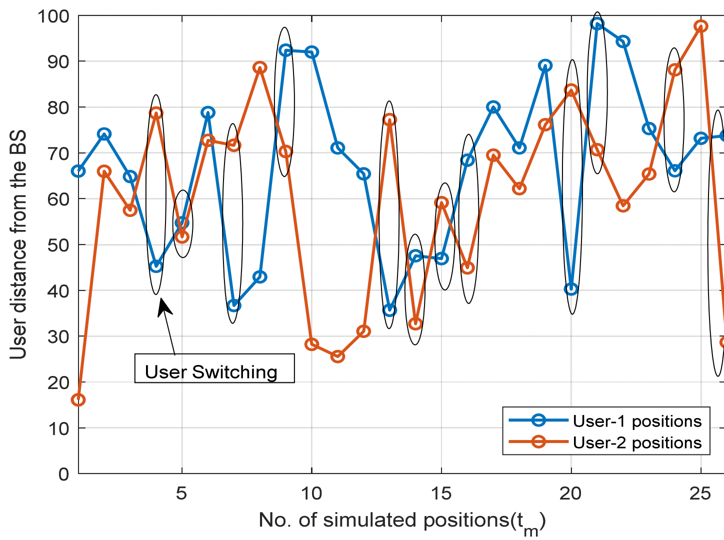


Figure 3 Shows the overall throughput of FPA-NOMA and DPA-NOMA with and/or without Im-SIC constraint for user-1 and user-2 respectively (see online version for colours)

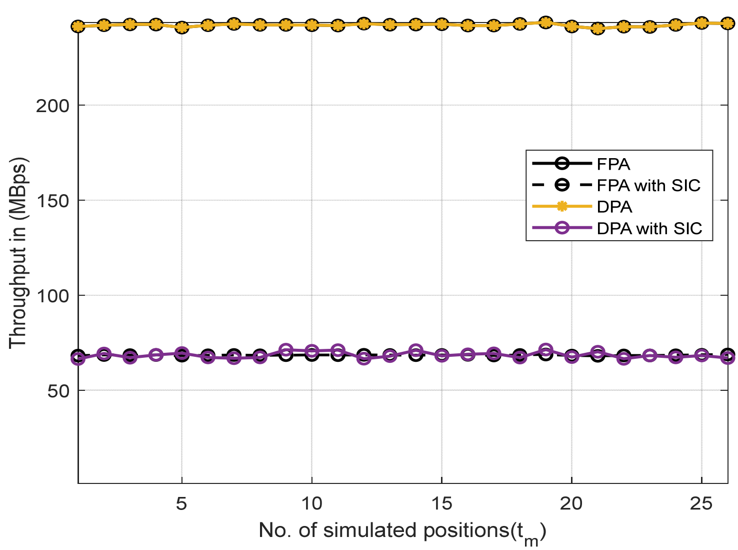


Figure 4 Shows the variation of fairness index v/s number of user positions (see online version for colours)

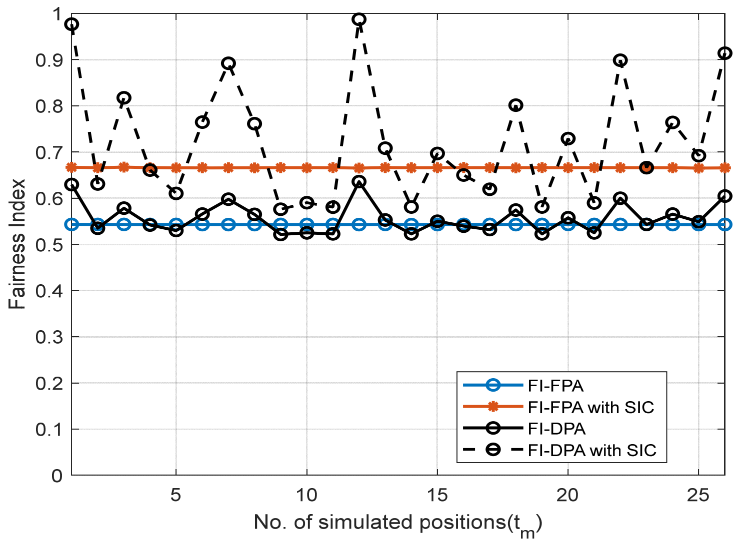
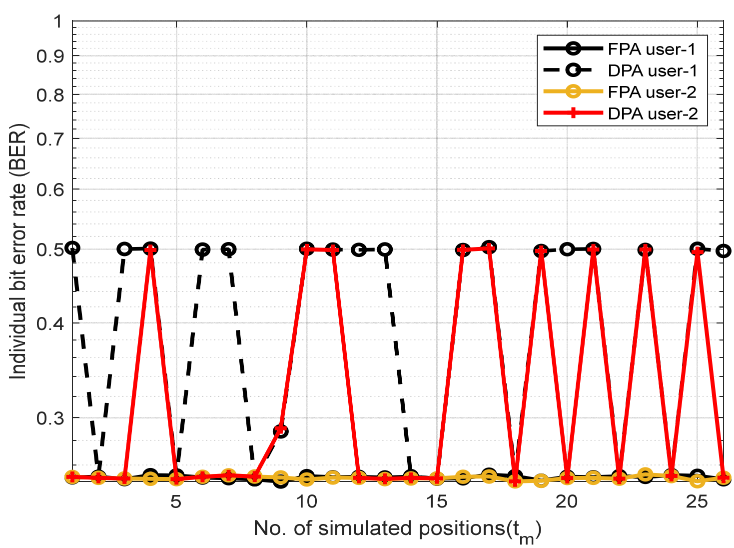


Figure 5 Shows the variation of average bit error rate v/s number of user position (see online version for colours)



For both FPA-NOMA and DPA-NOMA system, the overall throughput is achieved at user position (t_{19}), i.e., user-1 coordinates (–44.6752, 77.0747) and user-2 coordinates (32.6551, –68.8018) respectively at transmit power of 46 dBm. For perfect SIC, the overall throughput is nearly same for FPA-NOMA and DPA-NOMA (i.e., 243.46 Mbps). However, for Im-SIC, the overall throughput is 68.831 Mbps and 71.426 Mbps for FPA-NOMA and DPA-NOMA respectively. Figure 4 shows the variation of fairness index v/s no. of user positions for FPA-NOMA and DPA-NOMA. Due to the proper selection of power allocation coefficient, the fairness index of DPA-NOMA is higher in most of user positions. In terms of fairness index, DPA-NOMA shows an improvement of 2.60% as compared to FPA-NOMA. It is also noted that fairness index for Im-SIC constraints perform better than perfect SIC constraint. This is due to the fair power allocation between users even though overall system throughput is less for Im-SIC constraint. For Im-SIC, fairness index shows an improvement of 22.63% and 29.37% for FPA-NOMA and DPA-NOMA respectively. Figure 5 shows the variation of bit error rate for FPA-NOMA and DPA-NOMA at user positions. For perfect SIC, bit error rate is nearly same for both user-1 and user-2 however for Im-SIC, bit error rate fluctuates when the users rapidly switches/exchange its positions. Figures 6 and 7 show the variations of throughput v/s the number of user positions. For user-1, there is no impact of Im-SIC on throughput of FPA-NOMA and DPA-NOMA. However, there is significant impact of user switching on the performance of DPA-NOMA. For user-1, DPA-NOMA with or without Im-SIC achieved the highest throughput of 59.049 Mbps at user position (t_{12}) with coordinates (63.1433, –17.1137) whereas for FPA-NOMA with or without Im-SIC, the highest throughput achieved is 20.1114 Mbps at user positions (t_3) with coordinates (–54.4113, 35.2575). For user-2, there is significant impact of Im-SIC on the NOMA system. For perfect SIC, the highest throughput achieved is 466.82 Mbps and 476.15 Mbps for FPA-NOMA and DPA-NOMA at user position (t_{19}) with coordinates (32.6551, –68.8018). However, for Im-SIC, the highest throughput achieved is 117.60 Mbps at user position (t_{26}) with coordinates (22.5745, –17.6448) and 132.54 Mbps at user position (t_9) with coordinates (70.1470, 4.6652) for FPA-NOMA and DPA-NOMA respectively.

Figure 6 Shows the individual throughput (Mbps) v/s no. of user positions (user-1) (see online version for colours)

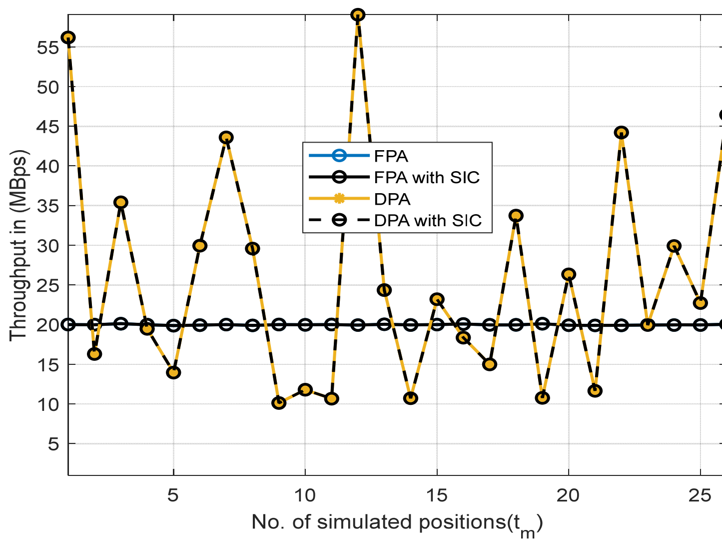
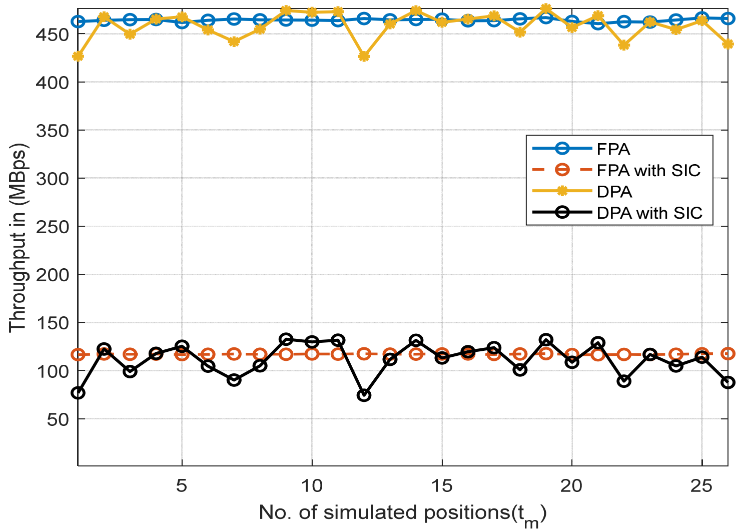


Figure 7 Shows the individual throughput (Mbps) v/s no. of user positions (user-2) (see online version for colours)



4 Conclusions

In this paper, the effects of user mobility and Im-SIC on the power allocation strategy for NOMA have been investigated by using three metrics, sum-rate capacity, fairness index, and bit error rate. In terms of the performance, the average system throughput is nearly the same for FPA-NOMA and DPA-NOMA with or without Im-SIC constraints. However, there is a significant reduced in system throughput of Im-SIC system as compare to perfect SIC system. In terms of fairness index, DPA-NOMA have better fairness index than FPA-NOMA in most of the user positions whereas in terms of bit error rate, DPA-NOMA shows fluctuation due to the users switching as compare to FPA-NOMA. The performance of the NOMA system depends on the various parameters such as perfect or Im-perfect channel conditions, user mobility and user switching which cannot be ignored while selecting power allocation strategy. The effect of user clustering or user pairing problems and SIC ordering challenges on the performance metrics parameters will be explored in our future research work.

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