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Spectrally Efficient UAV Communications using Non-Orthogonal Multiple Access (NOMA)

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ABSTRACT

Non-orthogonal multiple access (NOMA) scheme with its share of benefits such as spectral efficiency and simultaneous support of massive connectivity, is one of the keys enabling technologies for upcoming 5G. However, in the context of UAV-assisted communication, existing literature mainly focuses on conventional orthogonal multiple access (OMA) which limits the spectral efficiency and number of simultaneous connections. Existing technologies are using LTE that only can serve 1 user per resource block. The user capacity nowadays is increased, so the existing technologies should be improved to higher user capacity such as 4 users per resource block. This research project focuses on the design of NOMA scheme for multiple users aiming to maximize the system capacity and spectral efficiency of Unmanned Aerial Vehicle (UAV) hotspot with baseline model and to simultaneously support mobile users. The proposed NOMA multi-users model is then compared with baseline model of 2 users per resource block in NOMA and OMA. The proposed NOMA model increases spectral efficiency, higher throughput and improved user fairness. The project only focuses on downlink communication with stationary users. The parameters measured are Bit Error Rate, Sum Rate, and Spectral Efficiency that depend on power allocation, altitude of UAV,and distance between UAV and users. Based on the simulation results, NOMA which employs Fractional Transmit Power Allocation (FTPA) algorithm has better performance in terms of sum-rate and spectral efficiency compared to those of OMA by as much as 650%. Results are also presented for various NOMA power allocation algorithms.

1. Introduction

Unmanned aerial vehicles (UAVs), commonly known as drones, are aircraft that can be controlled from the ground and do not have a human pilot, crew, or passengers on board. Due to their ease of deployment, low maintenance costs, great mobility, and ability to hover, UAVs can be employed in a variety of applications [1].

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Unmanned aerial vehicles (UAVs) have been increasingly popular in civilian applications in recent years, including aerial surveillance, traffic management, photography, package delivery, and communication relay [2]. Wireless communication using unmanned aerial platforms is a promising method for achieving wireless coverage inlocations where terrestrial infrastructure is lacking or non-existent [3]. Sohail *et al.,* [4] present detailed research on the usage of unmanned aerial vehicles (UAVs) in wireless networks. They look at two primary UAV applications: airborne base stations and cellular-connected consumers. UAVs provide major challenges, applications, and basic unresolved concerns for each use case. They also go over mathematical tools and strategies for dealing with UAV problems and evaluating UAV-enabled wireless networks. Khawaja *et al.,* [5] provide a thorough review of current Air-to-Ground channel measurement studies, large and small-scale fading channel models, their limitations, and future research objectives for UAV communications situations. Zeng *et al.,* [6] investigate wireless communication facilitated by a UAV, in which a rotary-wing UAV is deployed to interact with multiple ground nodes (GNs). It wants to reduce total UAV energy consumption, which includes both propulsion and communication-related energy, while still meeting each GN's communication throughput requirements. Wireless technology that achieves seamless connection and high reliability/throughput for both air-to-air and air-to-ground wireless communications in the three-dimensional (3D) space is required to fulfil both the control and non-payload communication (CNPC) and payload communication requirements in a variety of UAV applications [7].

A few examples where UAV plays important role in providing access to communication in which the existing fixed radio base station are incapable of doing it are listed here. In case of a disaster, such as flooding can cause a fixed radio base station to break down and thus, the communication link with victims in the impacted areas will be cut off. This problem can be solved by replacing the base station with a drone that can carry a small temporary base station to re-establish communication links [8]. In other situation, user capacity of a base station will be overloaded at certain places during a mass event such as a carnival [3]. The existing base station cannot cater to the huge number of users. The solution for this problem can be an add-on drone with a temporary base station to cater to the extra demand of the users or to off-load certain capacity from the fixed base station to the temporary base station.

Most of the systems mentioned above do not specifically mention the type of air interface used for their UAV deployment. Normally, in wireless cellular communication, 2G, 3G, 4G or even 5G systems are employing OMA air interface as defined by the 3GPP [9-11]. However, the current 4G LTE system which employs Orthogonal Multiple Access (OMA) or specifically, OFDMA air interface has one resource block (RB) that is allocated for 1 user only which means the capacity to transmit data rate for more than 1 user is limited. The issue is becoming more critical once the number of users increase unexpectedly in any emergency or exceptional situations (e.g. concerts, disasters, etc). In contrast, Non-orthogonal Multiple Access (NOMA) air interface can provide one resource block for more than one user at a time. This is where NOMA capitalizes with higher spectral efficiency, throughput, and good user fairness. Thus, in this article, the authors have proposed various techniques of NOMA implementation for UAV base station serving multiple ground users. Apart from that, pairing of users is done up to 4 users in a resource block for comparison purposes with conventional pairing of 2 users in a resource block.

2. Literature Review

One of the most promising radio access technologies in next-generation wireless communications is non-orthogonal multiple access (NOMA). Compared to the existing de facto standard orthogonal multiple access (OMA) approach, orthogonal frequency division multiple access (OFDMA), NOMA offers several desirable potential benefits, including increased spectrum efficiency, reduced latency with excellent dependability, and huge connection. The basic concept of NOMA is to serve several users at the same time, frequency, and space. NOMA using the ideas of superposition coding at the transmitter and self-interference cancellation (SIC) at the receiver, many users may be serviced on a single time-frequency resource block [12]. Ding *et al.,* [13] looked at NOMA's downlink performance with randomly dispersed cellular subscribers. The NOMA technique is proven to result in considerable ergodic sum-rate performance increases using the analytical formulations offered. The assigned power and the desired data rate, on the other hand, may have a direct impact on outage performance, i.e., if the allocated power is lower than the needed power for successful transmission, the UE will experience an outage. Zhang *et al.,* [14] suggested a unique resource allocation strategy based on cooperative cellular networks for NOMA. NOMA users with excellent channel circumstances operate as group leaders in their proposed framework, and may therefore convey information to NOMA users with bad channel conditions. Despite the benefits of the suggested method for high-complexity devices, it should be highlighted that the reduced complexity of NB-IoT devices, power-saving mode, and extended discontinuous reception (eDRx) make information relaying (at the low-complexity device) impossible.

With the advent of the fifth-generation (5G) wireless communication era, UAVs have found a place in aiding wireless communication, which helps to improve the performance of 5G networks while also meeting user quality-of-service (QoS) criteria [7]. UAV-enabled communication uses UAVs as airborne base stations (BSs) [15,16] or relays [17,18] and is especially useful in emergency situations such as data traffic congestion or natural catastrophes. One significant benefit of UAV-enabled communications over terrestrial communications is that the channels between UAVs and ground nodes are often of good quality, as they are dominated by line-of-sight (LoS) linkages with a high likelihood [19-21]. Furthermore, by taking use of UAV's high mobility through suitable trajectory design, the communication performance of UAV-enabled communications may be increased [15-17]. Although such improvements can be made in unmanned ground vehicle (UGV) communications [22] [23], designing UAV trajectories has far fewer constraints than designing UGV routes, such as obstructions and road restrictions, giving UAV-enabled communications a greater degree of performance optimization freedom.

Current UAV communication mainly uses Orthogonal Multiple Access (OMA) in which it can only serves one user per resource block. By using Non-orthogonal Multiple Access (NOMA), spectral efficiency can be increased because it can serve more than one user per resource block. NOMA has a higher capacity compared to OMA. The higher the capacity, the higher the spectral efficiency [24].

For NOMA implementation, when a UAV base station is serving two users, namely user 1 (near user) and user 2 (far user), the UAV transmits superimposed signal which contains signals for both users. More power is allocated to user 2 which has lower downlink channel state information (CSI) due to its further distance from the UAV to ensure fairness is achieved. At the receiving side, successive-interference-cancellation (SIC) is used to detect the signals. User 2 signal which has greater transmit power but lower channel gain, is decoded first whilst treating user 1 signal as interference. Then, user 2 signal component is subtracted from the received superimposed signal to prepare for user 1 signal detection. Consequently, user 2 suffers from higher inter-user interference and user 2 detection error is passed on to user 1. Thus, sufficient power has to be allocated to the user who is detected first, i.e. user 2 [25].

Some notable effort by recent researchers have introduced NOMA as the potential air interface for UAV communication. Authors in [26] proposed a path-following algorithm to jointly optimize multiple variables such as UAV's altitude, transmit antenna beamwidth together with power and bandwidth resource allocation to multiple users. The UAV is deployed by pairing each near user with one of the far users in terms of NOMA implementation. It was evidently shown that by jointly optimizing all the parameters rather than a few sets of parameters, NOMA outperforms OMA and achieves a better rate gain. Another research on NOMA investigates the effect of imperfect CSI between the UAV and users upon UAV network energy efficiency [27]. Resource allocation is achieved through 2-step solution in which the UAV altitude is fixed in the UAV network. Firstly, a suboptimal algorithm is employed by determining power proportion factors for users assigned on the same subchannel in order to achieve subchannels and users matching. Then, the objective function was converted into a convex problem through successive convex approximation method.

Shi *et al.,* [28] propose an UAV-aided full-duplex NOMA (FD-NOMA) method to improve spectral efficiency. Another 2-step solution is introduced here by firstly, determining the initial power allocation of ground users, UAV and base station based on access-priority method. Secondly, subchannels are assigned to paired ground users and the UAV by a message-passing algorithm before fine-tuning of the ground users and the UAV transmit powers. It is also proven that the proposed method achieves better performance than existing OFDMA method in terms of spectral efficiency and access ratio of the ground users. Finally, researchers in [29] consider the impacts of different fading parameters of the Nakagami-*m* channel on the NOMA-based uplink/downlink UAV system. They found out that by using full-duplex at the UAV and SIC technique at the receivers, the system gains benefit from the capability of UAV relay to serve two-user pairs simultaneously without consuming more bandwidth. Their future concern is how to enhance the system design of NOMA-aided UAV systems to serve multiple pairs of users. It can be concluded that based on the authors' knowledge with regards to NOMA implementation for UAV communication, there is very little effort on pairing of more than 2 users in a resource block by existing researchers.

In this article, a single UAV flying base station serving multiple ground users by employing NOMA approach is considered. The contribution of this article is to justify the advantage of using NOMA techniques in implementing UAV-assisted communication as compared to using OMA technique in which significant improvement in terms of BER, sum-rate and spectral efficiency can be achieved. Secondly, it is also proven by our simulation results that by pairing more than 2 users in a resource block, as in our case, pairing of up to 3 and 4 users together, we can achieve much better rate gain as compared to pairing of 2 users only. Thirdly, performance evaluations among various NOMA techniques such EPA, FPA and FTPA have been done and it is found that FTPA technique is the most superior technique for implementation on UAV communications.

3. Methodology

3.1 System Model

Figure 1 shows the system model used for the simulation. A wireless network consisting of four NOMA users, numbered U_1, U_2, U_3 and U_4. d_1, d_2, d_3, and d_4 denote their respective distance from origin to user equipment such that, $d_1 > d_2 > d_3 > d_4$. Based on their distance, U_1 is the farthest user and also the weakest user, then U4 is the nearest user and the strongest user to the base station.

Let a_1 , a_2 , a_3 , and a_4 denote their respective power allocation coefficients. According to the principles of NOMA, the weakest users (farthest user) must be allocated the most power and the strongest user (nearest user) must be allocated the least power. Therefore, the power allocation coefficients must be ordered as $a_1 > a_2 > a_3 > a_4$. The sum of the power allocation coefficient must be equal to 1 [13]. The reason is to make sure that users that are closer to the cell edge has a fair share amount of received power as those that are closer to the base station. This is closely related to mitigating the near-far issues.

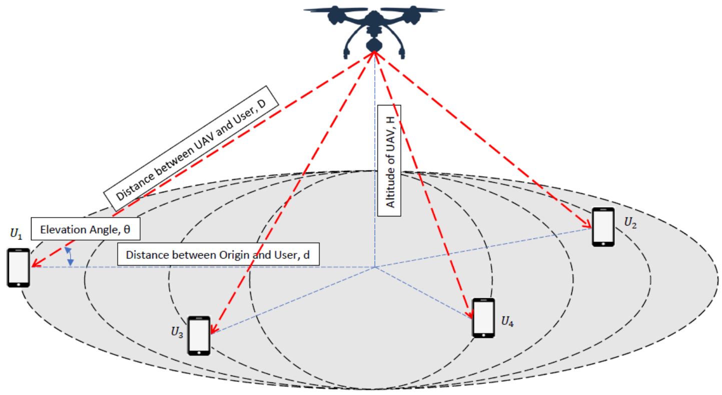

Fig. 1. UAV Communication system model

For this simulation experiment, three types of NOMA approaches have been examined to be used for UAV deployment, namely, Fixed Power Allocation (FPA), Equal Power Allocation (EPA) and Fractional Transmit Power Allocation (FTPA) [30]. The details of the 3 techniques are as follows:

i. For the FPA approach, the power allocation values for each user are fixed based on the distance of the users from the UAV base station. The closer the ground users to the UAV base station, the lower the power allocation factor.
ii. EPA technique facilitates the same power allocation factor for each individual users regardless of their distances to the UAV base station.
iii. Whereas for FTPA method, the power allocation is dynamic based on the users' channel condition so that fairness among all the users can be achieved. The channel condition is directly related to the users' distances from the UAV base station, in which, the closer the ground users to the UAV base station, the lower the power allocation values.

For all the three NOMA approaches, extensive Monte Carlo simulations have been done using Matlab in order to evaluate their performances in terms of bit error rate (BER), sum-rate and spectral efficiency.

The power allocation for Fixed Power Allocation (FPA) for 2 users, 3 users, and 4 users is shown in Table 1. The values were determined based on their distances from the UAV base station and the normalized values must be in between 0 and 1. The closer the user to the UAV base station, the lower the power allocation value. This means the power allocation values are set at ascending order as the ground users moving away from the UAV base station. For Equal Power Allocation (EPA), the power allocation coefficient is divided equally for each user. Fractional Transmit Power Allocation (FTPA) has different Rayleigh fading coefficient than the others. Its equation is:

$$H_N = \frac{{g_n}^{-a}}{N} \tag{1}$$

where a is the decay factor. For OMA, it does not use the power allocation method. The Rayleigh fading coefficient for EPA and FPA, h_n for each user, however, is given by:

$$h_n = \sqrt{{d_n}^{-eta}} * \left(randn(1, Nc) + j * randn(1, Nc)\right) \div \sqrt{2} \tag{2}$$

Channel gain for each user:

$$g_n = |h_n|^2 \tag{3}$$

The achievable rate is calculated by:

At User 1;
U1 has the highest power allocation coefficient and is the weakest user due to its farthest distance from the UAV base station, decoding of the received signal is done directly, treating U2, U3 and U4 as interference. The equation is shown below:

$$R_1 = Blog_2(1 + \frac{a_1(Pt)g_1}{a_2(Pt)g_1 + a_3(Pt)g_1 + a_4(Pt)g_1 + N}) \tag{4}$$

At User 2;
Since a2 > a3 > a4 but less than a1, U2 is the second weakest user and will implement SIC to subtract U1 whilst treating U3 and U4 as interference. After removing U1, the achievable rate is given by:

$$R_2 = Blog_2(1 + \frac{a_2(Pt)g_2}{a_3(Pt)g_2 + a_4(Pt)g_2 + N}) \tag{5}$$

At User 3;
As a3 > a4 and a3 < a2 < a1, U3 is the second strongest user and also will implement SIC to subtract U1 and U2 whilst treating U4 as interference. After removing U1 and U2, the achievable rate is given by:

$$R_3 = Blog_2(1 + \frac{a_3(Pt)g_3}{a_4(Pt)g_3 + N}) \tag{6}$$

At User 4;
U4 is the strongest user as he is the closest to the UAV base station. It has to perform SIC three times in order to remove U1, U2 and U3 from the superimposed received signal. Eventually, the achievable rate is given by:

$$R_4 = Blog_2(1 + \frac{a_4(Pt)g_4}{N}) \tag{7}$$

where N is noise power. The average of achievable rates also known as the individual rate of the user can be calculated using:

$$R_{nav} = mean(R_n) \tag{8}$$

The sum rate of the system can be calculated by total the individual rate of users.

$$Sumrate = R_{1av} + R_{2av} + R_{3av} + R_{4av} \tag{9}$$

The spectral efficiency, SE is equal to the sum rate divided by bandwidth, B.

$$SE = \frac{Sumrate}{B} \tag{10}$$

Table 1
Power Allocation Coefficient for FPA

User	a_n (2 users)	a_n (3 users)	a_n (4 users)
U_1 (500m)	0.70	0.60	0.70
U_2 (300m)	0.30	0.30	0.20
U_3 (200m)	-	0.10	0.15
U_4 (100m)	-	-	0.05

The received signal is calculated by:

$$y = \frac{(\sqrt{pt} * x_n * h_n)}{L_n} + n_n \tag{11}$$

where $x_n = \sqrt{a_{n1}} * xmod_{n1} + \sqrt{a_{n2}} * xmod_{n2}$ is the superposition coding to create the NOMA transmit signal. The h_n is Rayleigh fading coefficient. The L_n is path loss. The n_n is noise sample. The noise sample is generated by:

$$n_n = \sqrt{no} * (randn\left(\frac{N}{2}, 1\right) + i * randn(\frac{N}{2}, 1)) \div \sqrt{2} \tag{12}$$

Probability of a user experiencing a LOS link with UAV-BS:

$$Pr_j(LOS) = \frac{1}{1 + \alpha \exp(-\beta[\theta_j - \alpha])} \tag{13}$$

where α and β are constant values relating to the environment profile of the coverage region such as rural, sub-urban, dense urban etc. α is the ratio of land area covered by buildings to total land area (dimensionless) and β is the mean number of buildings per unit area (buildings/km^2) [31]. The parameter α and β ranging from 0.1 to 0.8 and from 100 to 750, respectively. Four different types of environments were selected for the scenarios presented here:

i. Suburban area
ii. Urban area
iii. Dense urban area
iv. Urban high-rise area

Table 2 shows the value of α and β to define the different types of environments ranging from suburban districts to city centre.

Probability of a user experiencing an NLOS link with UAV-BS [4]:

$$Pr_j(NLOS) = 1 - Pr_j(LOS) \tag{14}$$

Table 2
Parameters of the ITU-R P.1410 Model for Selected Environments (ITU-R, 2005)

Environment	α	B
Suburban	0.1	750
Urban	0.3	500
Dense Urban	0.5	300
Urban High-Rise	0.5	300

Considering the Downlink (DL) transmission, the received power by $j\ th$ user:

$$Prx, j(dB) = P_{tx}(dB) - L_j(dB) \tag{15}$$

where P_{tx} represents the transmitted power by the UAV-BS and L_j indicates the path loss for A2G channel between the UAV-BS and the $j\ th$ user on the ground,

$$L_j = \begin{cases} 10\eta \log(X_j) + x_{LOS}, & LOS\ link \\ 10\eta \log(X_j) + x_{NLOS}, & NLOS\ link \end{cases} \tag{16}$$

where η denotes the path loss exponent, x_{LOS} and x_{NLOS} represent the excessive path losses of both LOS and NLOS links owing to shadow fades, respectively [32]. The relationship in Eq. (15) is rewritten as:

$$Prx, j(dB) = P_{tx}(dB) - \overline{L_J}(R_c, H) \tag{17}$$

where $\overline{L_J}(R_c, H)$ defines the mean path loss considering probabilities for both LOS and NLOS UAV-user links computed as:

$$\overline{L_J}(R_c, H) = Pr_j(LOS)L_j(LOS) + Pr_j(NLOS)L_j(NLOS) \tag{18}$$

Table 3 summarises the implementation of necessary settings and parameters used in the overall Matlab simulation.

Table 3
Simulation parameters for UAV communication

Parameter	Value
Distance of U1, U2, U3, U4 from origin, d_n	500m, 300m, 200m, 100m
Altitude of UAV, *h*	100m
Path Loss Coefficient, *eta*	4
Transmit power, *pt*	30dBm
Bandwidth, *B*	1MHz

3.2 Flowchart of the Simulation Study

Figure 2 shows the flowchart of the overall simulation project. The research started with the development of a baseline model of NOMA in UAV communication for two users per resource block. Then, two more NOMA models with multi-users (3 users and 4 users per resource block) were created to investigate the effect of system performance by increasing number of users per resource block.

Next, the multi-user NOMA techniques (e.g. EPA, FPA and FTPA) were evaluated based on BER, sum-rate and spectral efficiency. Lastly, the multi-user NOMA models were compared with NOMA baseline model and also with OMA.

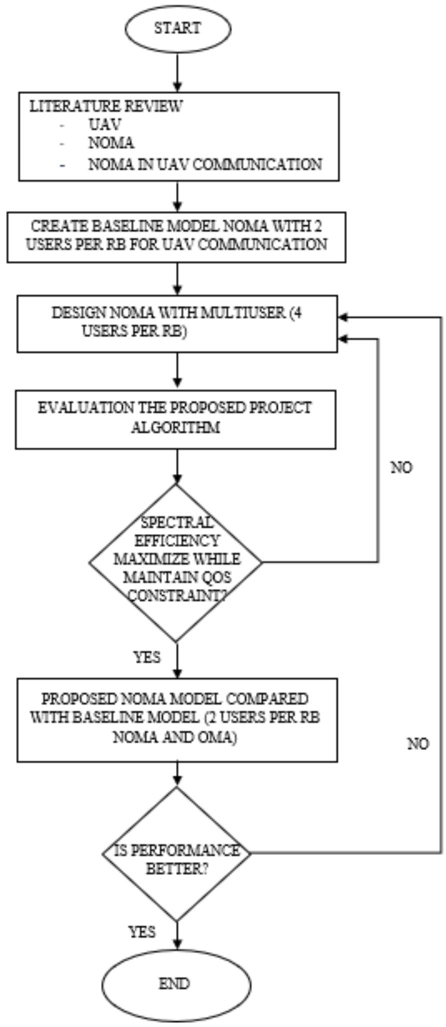

Fig. 2. Flowchart of overall simulation study

4. Results

In this section, Figure 1 has been used as the UAV-enabled base station simulation topology in which OMA and NOMA with FPA, EPA and FTPA power allocation algorithm for 2, 3, and 4 users were analysed. Bit error rate, sum rate and spectral efficiency have been evaluated using MATLAB simulations.

4.1 Bit Error Rate (BER)
4.1.1 Fixed UAV altitude (h = 100 m)

The simulation results shown here are obtained by comparing two NOMA allocation techniques, namely FPA and EPA, by having the UAV altitude at a fixed height of 100m. Figure 3 shows the BER versus Transmit Power for 2 users of FPA and EPA. The User 2 EPA have the lowest BER, followed by User 2 FPA, User 1 FPA, and then User 1 EPA. User 1 has a higher BER compared to user 2. This is because it suffers the most interference. User 2 causes interference for User 1. User 2 is free from interference and the lower BER. The other reason that the far user experiences more BER than the near user is the path loss experienced by each user is inversely proportional to at least the square of the distance between the UAV base station and the user. The farther the distance between the UAV base station and the user, the received power will be degraded exponentially. The BER performance is also affected by the power allocation coefficient used. Based on the average value of User 1 and User 2, the FPA have the better quality than EPA.

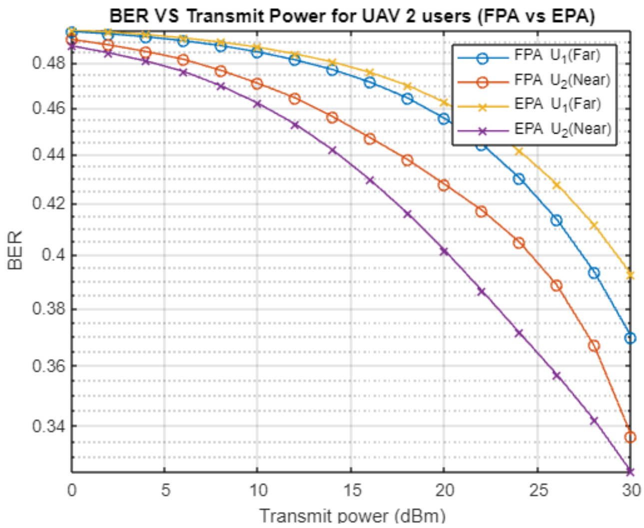

Fig. 3. Figure with short caption

Figure 4 displays the BER versus Transmit Power for 3 users of FPA and EPA. The User 3 EPA have the lowest BER, followed by User 3 FPA, User 2 EPA, User 2 FPA, User 1 FPA and then User 1 EPA. The User 3 EPA has the lowest BER, but after 26dBm User 3 FPA has the lowest BER. User 1 has a higher BER compared to User 2 and User 3. This is because it suffers the most interference. User 2 and User 3 cause interference for User 1 and User 3 cause interference for User 2. User 3 is free from interference and the lower BER. The User 2 and 3 EPA increase gradually at 26dBm and the User 3 FPA have the lowest BER due to it have the better power allocation and nearest to the base station.

Figure 5 indicates the BER vs Transmit Power for 4 users of FPA and EPA. User 4 EPA have lowest BER, followed by User 4 FPA, User 3 EPA, User 3 FPA, User 2 EPA, User 2 FPA, User 1 FPA, and then User 1 EPA. The User 4 EPA has the lowest BER, but after 26 dBm User 4 FPA has the lowest BER. It due to the increase of capacity, the interference also increases. User 1 has a higher BER compared to User 2, User 3, and User 4. This is because it suffers the most interference. User 2, User 3, and User 4 cause interference for User 1, User 3, and User 4 cause interference for User 2, and User 4 cause interference for User 3. User 4 is free from interference and the lower BER. The User 3 and 4 EPA have the changes of BER at 18dBm. This because of the transmit power increase, not only the received power of intended user increase, the received power of other users also increases. The interference will increase and cause the error increase for the intended user or other users.

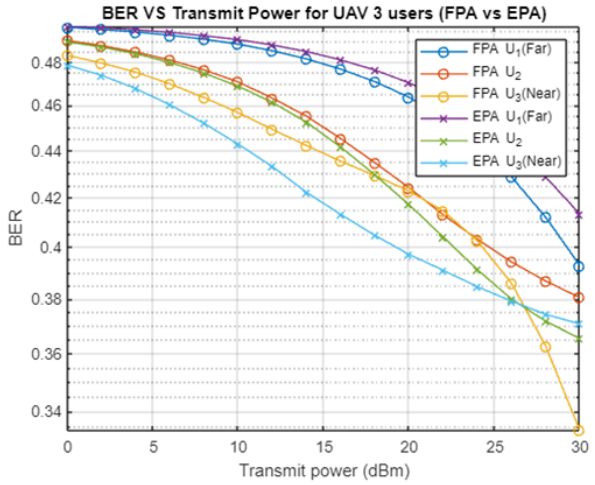

Fig. 4. BER versus transmit power for 3 users

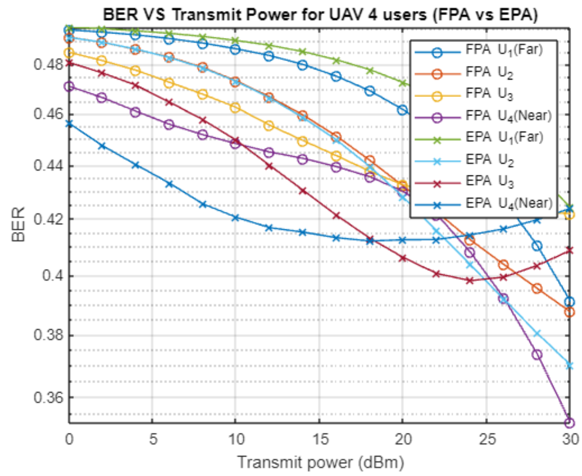

Fig. 5. BER versus transmit power for 4 users

4.1.2 FPA and variable UAV altitude (h = 100m, 300m, 500m)

For the following scenario, the UAV altitudes are varied for three different heights from the ground whilst using FPA technique for all the ground users. Based on Figure 6 with UAV altitude of 100m, User 4 have lowest BER, followed by User 3, User 2, and then User 1. When the transmit power goes beyond 24dBm, the BER of all the users are now being swapped accordingly with User 1 has the lowest BER followed by User 2, User 3 and User 4. This is because at low transmit power, the furthest user (User 1) will experience the lowest signal reception and so the highest BER but as the transmit power is increased beyond a threshold level (e.g. 24dBm), it will start to gain better signal reception and thus, the lowest BER.

As the UAV altitude is increased to 300m, the same pattern of BER for all users is shown in Figure 7 as it is in Figure 6. Only after the transmit power reaches 20dBm, the BER for all the users are again swapped accordingly. It can be observed that the BER values in Figure 7 are slightly higher compared to those in Figure 6 because as the UAV altitude is increased the distance between the UAV and the ground users are also increased, contributing to more path loss between them. Lastly, in Figure 8, the same pattern is shown here as in the previous figures and the highest BER values are also observed in the figure as the UAV altitude is increased to 500m above the ground. Obviously, this is the furthest distance between the ground users and the UAV among the three figures and thus, the highest path loss is contributed in this event.

Based on the results shown in the figures, it can be concluded that the higher the UAV altitude, the weaker the transmit power from the UAV to the respective ground users and thus, the higher the BER of all the users. Comparing the three UAV altitudes, the UAV altitude of 100m produces the best performance in terms of BER. With low BER which means low data loss, more data rate can be transmitted from the UAV to the ground users and thus, will contribute to better sum-rates and spectral efficiency.

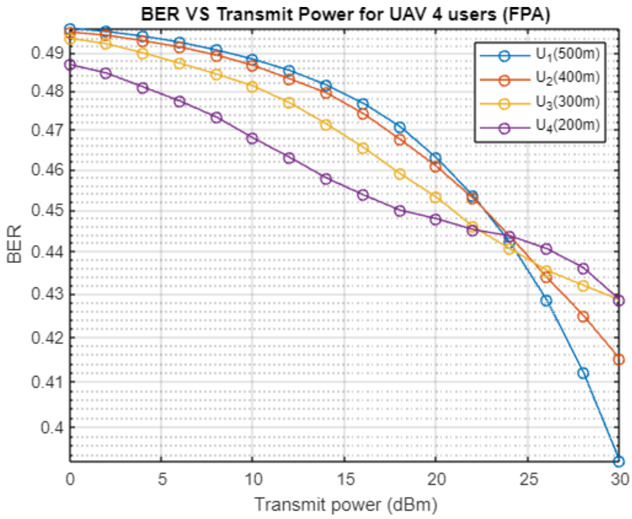

Fig. 6. BER versus transmit power for 4 users (UAV altitude = 100m)

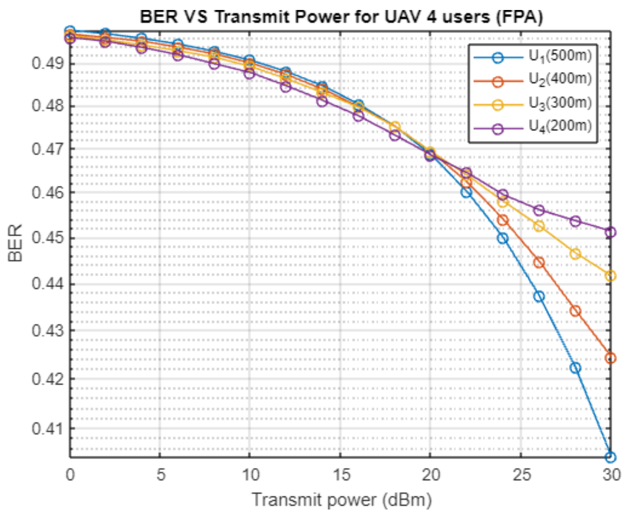

Fig. 7. BER versus transmit power for 4 users (UAV altitude = 300m)

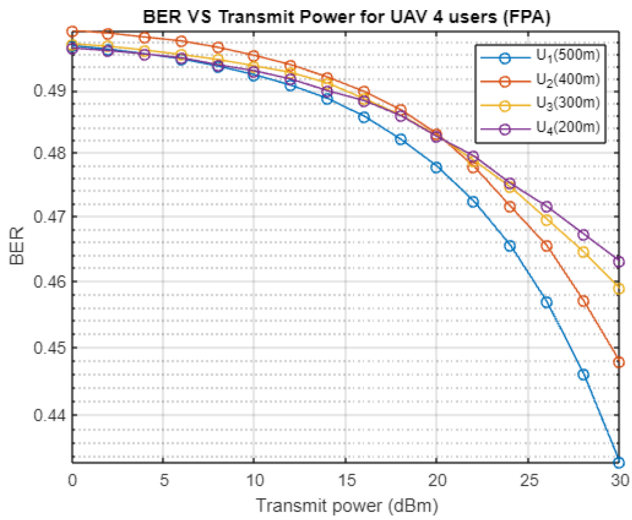

Fig. 8. BER versus transmit power for 4 users (UAV altitude = 500m)

4.2 Sum-Rate

Figure 9 shows that the sum rate of the system increases with the increase in transmit power for all power allocation algorithm. On the other hand, FTPA achieves a higher sum rate than FPA, EPA and OMA, while FPA performs better EPA due to the dependability of channel conditions in assigning the power levels, which is not considered in EPA. Though FTPA achieves the best performance, it has higher complexity especially with the increased number of users sharing the same subchannel. Comparing the performance of FTPA among the 2 users, 3 users and 4 users, it is observed that the highest sum-rate is achieved when signals for 4 users are superimposed together. This shows that superimposing more than 2 users are realizable and produces much higher sum-rate.

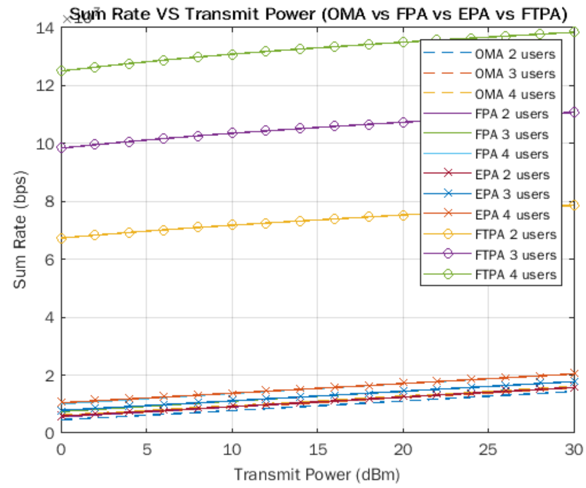

Fig. 9. Sum-rate versus transmit power

4.3 Spectral Efficiency

Figure 10 shows the performance of the system as a function of spectral efficiency versus the transmitted power. The same pattern is observed here as seen in Figure 9 earlier. This is because the spectral efficiency has a direct relationship with the sum-rate by dividing the latter with the transmission bandwidth. The spectral efficiency increases as the transmitted power grow. From the figure, the best performance of the four-user power allocation algorithm is achieved when the transmitted power is 30dBm. FTPA outperforms the other power allocation algorithm due to the choosing the best pair of power levels that provide the best performance among the other solutions. Moreover, FPA and EPA performs better than the OMA which can be related to the use of power allocation in FPA and EPA. FPA and EPA seen to be overlapped, but the FPA have slightly higher than the EPA due to the power coefficient of EPA is not fair for far user have the same value of power with near user.

The results portrayed in the simulation show that NOMA performs much better than OMA in terms of sum-rate and spectral efficiency and then, FTPA, which is one of the three NOMA techniques under investigation, outperforms FPA and EPA techniques in terms of BER. In the near future, the simulation results will be validated through testbed experimentation.

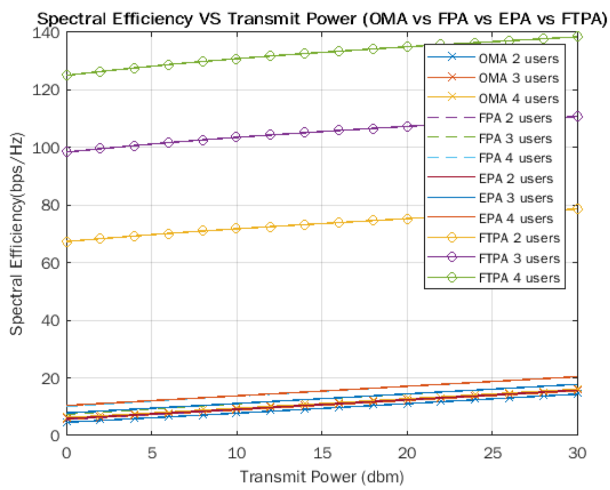

Fig. 10. Spectral efficiency versus transmit power

4. Conclusions

In conclusion, this project is about investigating spectral efficiency by implementation of NOMA techniques for UAV communications. NOMA can be considered for use in 5G communication which can serve two or more users in the same frequency and time domain but differentiated it by power domain. This technology can cater huge number of users compared to OMA. By increasing the transmit power, the transmission will result in increase in sum rate and decrease in bit error rate. The transmit power increase, the signal power will be increased as compared to noise power. Because the noise power remains the same, but as the transmit power is increased, the signal power will then increase, so the signal to noise ratio will become larger, more packet or information can be transmitted to the channel toward the receiver. The NOMA have higher spectral efficiency than OMA based on the result.

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