When UAV and Ad-Hoc NOMA-BS Meets in Disaster: A Scheduling and Mode Selection Approach

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Abstract- With the recent growth in wireless communication, non-orthogonal multiple access (NOMA) plays an essential role in the 5G network. In the event of natural disasters protecting the life of peoples has been playing an important role around the world. Natural disasters cannot be bypassed, but their effect can be mitigated by a comprehensive network model of the disaster management system. In this paper, an unmanned aerial vehicle (UAV) and ad-hoc NOMA-BS can be applied for serving the ground users in a non-functional area (NFA) or disaster area. Disaster areas can be divided into two, such as wide area and confined areas. However, a UAV can communicate to ground users based on line-of-sight (LoS) and non-line-of-sight (NLoS) in a wide area using a scheduling approach. Also, an ad-hoc NOMA-BS can serve NOMA signal to ground users in a confined area. Furthermore, a mode selection algorithm can be applied for the users to determine whether they are nearer to UAV and ad-hoc NOMA BS or not. The expression for coverage probability and average rate are developed in our proposed UAV-assisted NOMA network. The outage probability, coverage probability, and average rate are investigated for several network parameters. Finally, results are shown via simulation in MATLAB.

Keywords- Unmanned Aerial Vehicle, Non-Orthogonal Multiple Access, Non-functional Area, Coverage Probability, and Sum rate

1. INTRODUCTION

In an ongoing demand, built-in massive connections and utilization of spectrum efficiency are becoming the primary challenges for the 5G networks [1]. In a world, the large scale of natural disasters is increasing daily [2]. Recent research has seen that unmanned aerial vehicles (UAV) have the power to rescue people in an NFA or disaster area [3]. In both academia and industry, UAV-based solution has been becoming fascinated everywhere. In a disaster environment, UAV can escort the rescuers with its bird's-eye view, and it can manage data collection, victim localization, and rescue people [4,5]. In [6], authors have studied ground user communication through a UAV-assisted relay network to minimize the network's energy consumption. In [7], authors have investigated UAV-assisted communication for disaster management using a Fruit Fly optimization clustering algorithm. In [8], authors have shown that UAV provides ground node coverage in post-disaster scenarios and evaluates the optimal relay hops of the device-to-device (D2D) wireless network. Currently, D2D communication can be a good solution for disaster management. In [9], authors have studied the disaster recovery operation using D2D communication utilizing smartphones. Smart disaster recovery includes multi-channel hopping and energy awareness on the demand distance vector of the network. In [10], the authors have discussed detecting isolated nodes using D2D and reconnecting the isolated nodes in the disaster zone. In [11], the authors have studied the D2D communication for network users and service requirements in a post-disaster scenario.

Furthermore, NOMA can be applied to the disaster management system [12]. Also, NOMA is an efficient candidate for a 5G wireless communication system [13]. In [14], authors have studied NOMA-based D2D networks considering multiple interference cancellation (MIC) schemes at the receiver side and finding out the energy efficiency (EE) and fairness factor. In [15], the authors have discussed NOMA with simultaneous wireless information and a power transfer-enabled network for improving spectral efficiency and EE. In [16], authors have studied the two-hop NOMA relaying network and developed a golden section search-based algorithm for the optimization problem. In [17], the authors have discussed D2D communication using network coding and considered the mode selection algorithm in the network. In [18], the authors have discussed UAV-assisted NOMA networks' throughput performance and optimization for disaster management. In [19], authors have considered static and mobile UAVs for downlink UAV-assisted D2D networks. In [20], authors have considered a UAV-assisted NOMA network using a joint trajectory and optimization technique.

1.1 Contribution

In [19], authors have considered a UAV-assisted

D2D network for the non-disaster scenario. Our proposed work investigates a UAV-assisted ad-hoc NOMA-based cellular network for the disaster scenario. In our scenario, we have considered UAV based cellular network using a scheduling approach in a wide area. Also, we have considered ad-hoc NOMA-BS in the confined area.

The contributions can be described as follows:

- The analytical expression for the outage probability and coverage probability are developed in our proposed network.
- The average and total data rates have been evaluated in both wide and confined areas.
- The Mode selection algorithm has been developed for the ground user.

1.2 Organization of the paper

The considered system model and the performance analysis are discussed in Section 2. Results are described in Section 3. At last, the conclusion is made in Section 4.

2. SYSTEM MODEL

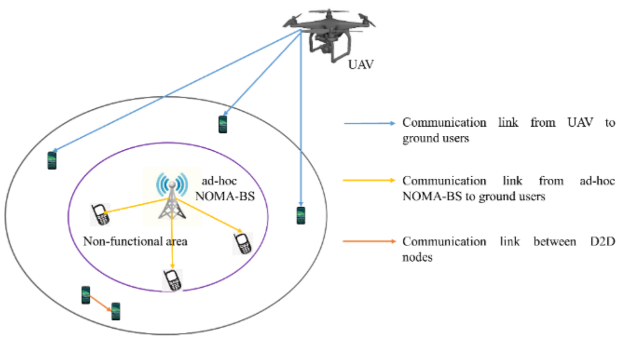

Figure 1. System model for communication in disaster area from UAV and NOMA-BS

Figure 1 shows that NOMA-BS and UAV serve the ground users in the UAV-assisted NOMA-based cellular network. The UAV is placed at the altitude $\hbar$ in the wide area. The UAV serves the L number of uniformly distributed ground users based on LoS and NLOS in a wide area. The radius of the wide area is denoted as r. An ad-hoc NOMA-BS serves NOMA signal to the Q number of ground users in a confined area. In addition, if any one of the ground users is not nearer to the UAV and the NOMA-BS, they will communicate as a D2D node. This system model considers a downlink scenario for the UAV and NOMA-BS.

2.1. Air to ground communication

The ground user receives information based on LoS, and NLoS. In [5], the modeling of air-to-ground channel propagation considers LoS and NLoS occurrence probabilities separately. The received signal at the user location from the UAV based on LoS or NLoS connection can be given as:

$$\boldsymbol{P_U = \begin{cases} P_u|d_u|^{-m} & LoS \\ \eta P_u|d_u|^{-m} & NLoS \end{cases}} \quad \textbf{(1)}$$

where P_u represents transmit power of UAV, d_u is the distance between the UAV and ground users, m is the path-loss exponent, and η denotes the attenuation factor. The LoS probability can be expressed in [9]:

$$\mathbb{P}_{LoS} = \frac{1}{1+a\, exp(-b[\theta-a])} \quad (2)$$

where a and b are constant values and θ is the elevation angle, $\theta = \frac{180}{\pi} \times sin^{-}\left(\frac{\hbar}{|d_u|}\right)$, $|d_u| = \sqrt{\hbar^2 + r^2}$ and the probability of NLoS is $\mathbb{P}_{NLoS} = 1 - \mathbb{P}_{LoS}$. Furthermore, we define a scheduling approach for the UAV i.e., $s_l[n] \in \{0,1\}$ where $s_l[n] = 0$ means the UAV do not serve the l^{th} user at the n^{th} time slot, but when $s_l[n] = 1$, it means UAV serves the l^{th} user at the n^{th} time slot. So, assume that $s_l[n] = 1, \forall l \in L$, during this time slot, the l^{th} user served by the UAV.

At the l^{th} user, the received signal to interference noise ratio ($SINR$) is denoted as γ_u and it can be expressed as:

$$\gamma_u = \frac{P_U|h_u|^2}{I_D+\sigma_n^2} \quad (3)$$

where $I_D = P_{U'}|h_{u'}|^2$, h_u represents channel fading coefficient, I_D is the interference from other users, and σ_n^2 denotes the noise power.

At l^{th} user, the average rate over the $\mathcal{T}$ time slots can be expressed:

$$\mathcal{R}_{u,l} = \frac{1}{\mathcal{T}}\sum_{n=1}^{\mathcal{T}} s_l[n] log_2\left(1 + \frac{P_U|h_u|^2}{I_D+\sigma_n^2}\right) \quad (4)$$

2.1.1. Coverage Probability

In the case of upper and lower bound, the average coverage probability for downlink users can be expressed as [20]:

$$\mathbb{P}_{cov,L}(\gamma_{th},h) = \int_0^R \mathbb{P}_{LoS}(r,\gamma_{th})\, L_I\left(\frac{P_u|d_u|^{-m}}{\gamma_{th}} - \sigma_n^2\right)\frac{2r}{R^2}dr + \int_0^R \mathbb{P}_{NLoS}(r,\gamma_{th})\, L_I\left(\frac{\eta P_u|d_u|^{-m}}{\gamma_{th}} - \sigma_n^2\right)\frac{2r}{R^2}dr \quad (5)$$

where R is the radius of desired wide area and γ_{th} is the $SINR$ threshold.

$$\mathbb{P}_{cov,U}(\gamma_{th},h) = \int_0^R \mathbb{P}_{LoS}(r,\gamma_{th})\, U_I\left(\frac{P_u|d_u|^{-m}}{\gamma_{th}} - \sigma_n^2\right)\frac{2r}{R^2}dr + \int_0^R \mathbb{P}_{NLoS}(r,\gamma_{th})\, U_I\left(\frac{\eta P_u|d_u|^{-m}}{\gamma_{th}} - \sigma_n^2\right)\frac{2r}{R^2}dr \quad (6)$$

where $\gamma_{th}\sigma_n^2 < P_u\left||d_u|\right|^{-m}$, and for any $T > 0$. $L_I(T)$, and $U_I(T)$ are defined in [19].

Now, the average coverage probability can be represented as:

$$\mathbb{P}_{cov,Du}(\gamma_{th}) = \int_0^{\min\left[\left(\frac{P_u}{\gamma_{th}\sigma_n^2}\right)^{1/m},R\right]} \mathbb{P}_{Los}(r)\frac{2r}{R^2}dr + \int_0^{min\left[\left(\frac{\eta P_u}{\gamma_{th}\sigma_n^2}\right)^{1/m},R\right]} \mathbb{P}_{Los}(r)\frac{2r}{R^2}dr \quad (7)$$

The coverage probability can be denoted as:

$$\mathbb{P}_{cov,Du}(r,\gamma_{th}) = \mathbb{P}[\gamma_u \geq \gamma_{th}] \quad (8)$$

$$\mathbb{P}_{cov,Du}(r,\gamma_{th}) = \mathbb{P}_{LoS}(r)\mathbb{P}[\gamma_u \geq \gamma_{th}|LoS] + \mathbb{P}_{NLoS}(r)\mathbb{P}[\gamma_u \geq \gamma_{th}|NLoS] \quad (9)$$

The outage probability can be expressed as:

$$\mathbb{P}_{out} = 1 - \mathbb{P}_{cov,Du}(r,\gamma_{th}) \quad (10)$$

2.2. NOMA-BS to ground user Communication

A downlink NOMA-BS communicates to q^{th} the user at subcarrier z . The channel gain $g_{q,z} = \left|h_{q,z}\right|^2 d_q^{-m}$, where $g_{q,z}$ denotes the channel fading coefficient and it follows identically independent distributed exponential random variables with a mean of 1, for every subcarrier. d_q represents the distance between q^{th} user and the NOMA-BS. The distances are categorized as $d_1 > d_2 > \cdots > d_q > \cdots > d_Q$ without loss of generality. In [3], the successive interference cancellation (SIC) is being utilized at the receiver side, it detects the strongest signal and considers other as interference. In the further stage, the strongest signal is removed from the composite signal; after that, the second strongest signal is decoded and cancelled. As long as the weakest signal is decoded, the process is continued. In the case of the SIC process, user 1 is the strongest signal detected and removed. Subsequently, the same for user 2 is detected and cancelled and this process is repeated until the signal of user $q-1$ is detected and cancelled.

In the confined area, the $SINR$ for the q^{th} user at subcarrier z is denoted as $\gamma_{q,z}$, and it can be expressed as:

$$\gamma_{q,z} = \begin{cases} \frac{P_{q,z}h_{q,z}}{h_{q,z}\sum_{j=q+1}^{Q} P_{j,z}+\sigma_c^2}, & q \in 1,2,\dots,Q \\ \frac{P_{Q,z}h_{Q,z}}{\sigma_c^2}, & q = Q \end{cases} \quad (11)$$

where $P_{q,z}$ denotes the transmit power allocation of the q^{th} user, and σ_c^2 represents noise power in the confined area.

2.2.1. Outage Probability

The outage probability expressions are determined for user 1 and user 2. Assuming users 1 and 2 are far and closer to the NOMA-BS. The data rates for far and near users are observed after the SIC at the receiver side:

$$\mathcal{R}_{1,z} = log\left(1 + \frac{P_{1,z}h_{1,z}}{P_{2,z}h_{1,z}+\sigma^2}\right) \quad (12)$$

$$\mathcal{R}_{2,z} = log\left(1 + \frac{P_{2,z}h_{2,z}}{\sigma^2}\right) \quad (13)$$

The total data rate for far and near users can be expressed after adding the data rates on all the subcarriers

$$\mathcal{R}_1 = \sum_{z=1}^{Z} log\left(1 + \frac{P_{1,z}h_{1,z}}{P_{2,z}h_{1,z}+\sigma^2}\right) \quad (14)$$

$$\mathcal{R}_2 = \sum_{z=1}^{Z} log\left(1 + \frac{P_{2,z}h_{2,z}}{\sigma^2}\right) \quad (15)$$

The outage probability for user 1 defines the probability of the total data rate $\mathcal{R}_1$ falling below the target rate of user 1:

$$\mathbb{P}_{out_{1,z}} = \mathbb{P}(\mathcal{R}_1 \leq r_1) \quad (16)$$

$$\mathcal{R}_1 = \sum_{z=1}^{Z} log\left(1 + \frac{P_{1,z}g_{1,z}d_1^{-m}}{P_{2,z}g_{1,z}d_1^{-m}+\sigma^2}\right) \quad (17)$$

$$\mathcal{R}_1 = \sum_{z=1}^{Z} log\left(\frac{\sigma^2+(P_{1,z}+P_{2,z})g_{1,z}d_1^{-m}}{\sigma^2+P_{2,z}g_{1,z}d_1^{-m}}\right) \quad (18)$$

$$\mathbb{P}_{out_{1,z}} = \mathbb{P}\left(\sum_{z=1}^{Z} log\left(\frac{\sigma^2+(P_{1,z}+P_{2,z})g_{1,z}d_1^{-m}}{\sigma^2+P_{2,z}g_{1,z}d_1^{-m}}\right) \leq r_1\right) \quad (19)$$

$$\mathbb{P}_{out_{1,z}} = \mathbb{P}\left(\prod_{z=1}^{Z}\left(\frac{\sigma^2+(P_{1,z}+P_{2,z})g_{1,z}d_1^{-m}}{\sigma^2+P_{2,z}g_{1,z}d_1^{-m}}\right) \leq e^{r_1}\right) \quad (20)$$

Now, the outage probability for user 2 can be defined as

$$\mathbb{P}_{out_{2,Z}} = 1 - \mathbb{P}_{suc_{2,Z}} \times \mathbb{P}_{suc_{1\to 2,Z}} \quad (21)$$

where $\mathbb{P}^{suc}_{2,Z}$ represents the success probability and $\mathbb{P}^{suc}_{1\to 2,Z}$ denotes the probability of the success event detecting the message of user 1. They are expressed as:

$$\mathbb{P}^{suc}_{2,Z} = \mathbb{P}(\mathcal{R}_2 > r_2) \quad (22)$$

$$\mathbb{P}^{suc}_{1\to 2,Z} = \mathbb{P}(\mathcal{R}_{1\to 2} > r_{1\to 2}) \quad (23)$$

where $\mathcal{R}_{1\to 2} = \sum_{z=1}^{Z} log\left(1 + \frac{P_{1,z}h_{2,z}}{P_{2,z}h_{2,z}+\sigma^2}\right)$, and $r_{1\to 2}$ denotes target rate.

Now, the total data rate can be evaluated for each user considering all the shared subcarriers [20]:

$$\mathcal{R}_q = \begin{cases} \frac{P_{q,z}h_{q,z}}{h_{q,z}\sum_{j=q+1}^{Q} P_{j,z}+\sigma_c^2}, & q \in 1,2,\dots,Q-1 \\ \frac{P_{Q,z}h_{Q,z}}{\sigma_c^2}, & q = Q \end{cases}$$

(24)

$$\mathcal{R}_q = \begin{cases} \sum_{q=1}^{Q} log\left(1 + \frac{P_{q,z}h_{q,z}}{h_{q,z}\sum_{j=q+1}^{Q} P_{j,z}+\sigma_c^2}\right), & q \in 1,2,\dots,Q-1 \\ \sum_{q=1}^{Q} log\left(1 + \frac{P_{Q,z}h_{Q,z}}{\sigma_c^2}\right), & q = Q \end{cases}$$

(25)

For user q, the outage probability can be expressed as:

$$\mathbb{P}^{out}_{q,Z} = 1 - \mathbb{P}^{suc}_{q,Z} \times \sum_{j=1}^{q-1} \mathbb{P}^{suc}_{j\to q,Q} \quad (26)$$

Algorithm: Mode Selection
1. Initialization: $\boldsymbol{L}$, $\boldsymbol{Q}$, $\boldsymbol{d_{u,max}}$, and $\boldsymbol{d_{q,max}}$
2. for $\boldsymbol{i = 1{:}L}$
3. Calculate $\boldsymbol{d}$
4. if $\boldsymbol{d > d_{u,max}}$ && $\boldsymbol{d > d_{c,max}}$
5. mode(i)←D2D node
6. else if $\boldsymbol{d < d_{u,max}}$
7. mode(i)← UAV assisted node
8. else if $\boldsymbol{d < d_{c,max}}$
9. mode(i)← NOMA-BS connected node
10. end if
11. end if
12. end if
13. end for

3. RESULTS AND DISCUSSIONS

In this section, the numerical results using the performance analysis have been shown. The outage probability, coverage probability, and average rate have been evaluated via simulation. The results have been shown using a Monte Carlo simulation which is performed in MATLAB. The values of some network parameters are considered as $P_u = 30$ dBm, $r = 500$ m, $\hbar = 50$ m, $\gamma_{th} = -20$ dB, and $\mathcal{T} = 40$ ms for evaluation of network performances. Figure 2. shows the variation of outage probability for several values of γ_{th} in a wide area. The outage probability increases as the γ_{th} increases for a fixed P_u. For a particular γ_{th}, the outage probability decreases as the P_u increases. If P_u increases, then the received γ_u increases, thus the outage probability decreases

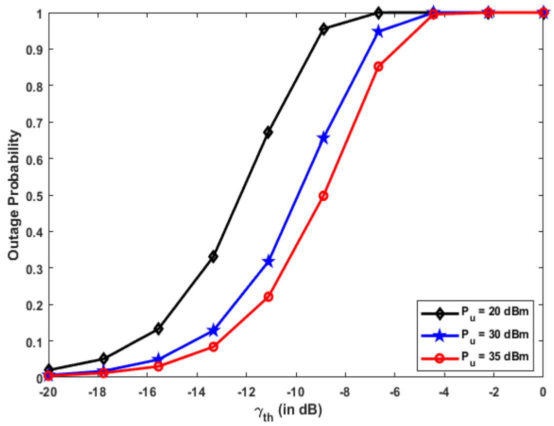

Figure 2. Variation of outage probability for several values of $\boldsymbol{\gamma_{th}}$

In Figure 3, the coverage probability has been plotted for different values of γ_{th}. It is shown that the coverage probability decreases as the $SINR$ threshold increases. However, if the radius of the wide-area decreases, then the coverage probability increases. The analytical and simulation results are well verified.

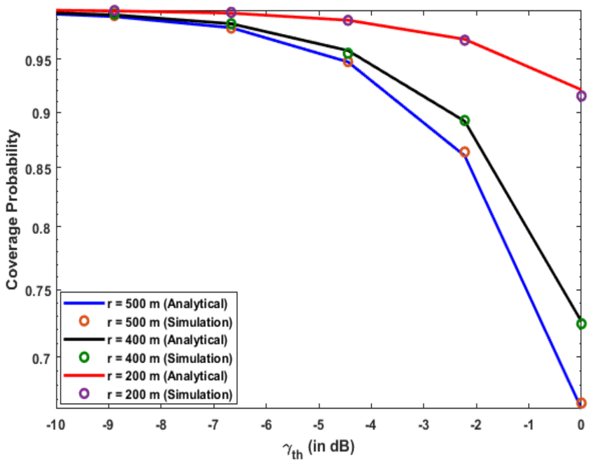

Figure 3. Coverage probability vs. γ_{th} (dB)

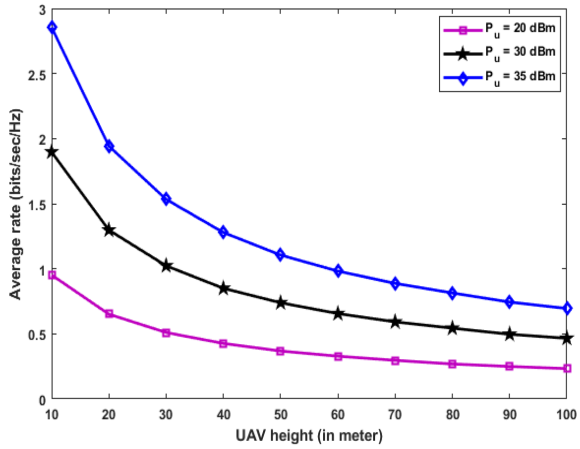

Figure 4. The average rate vs. UAV height

Figure 4. illustrates the average rate vs. UAV height considered for the wide area. The average rate is obtained by using equation (4). If the UAV height increases then the received power decreases; as a result, $SINR$ decreases. If the $SINR$ decreases, then the average rate decreases. It is also shown that if the power of UAV increases, then the received $SINR$ increases. If the received $SINR$ increases, then the average rate increases. Figure 5. shows the outage probability vs. target rate in the confined area. It is investigated that if the target rate increases, the outage probability increases. It is shown that if the power of the far user increases, the $SINR$ increases. So, if the $SINR$ increases, as a result, the outage probability decreases.

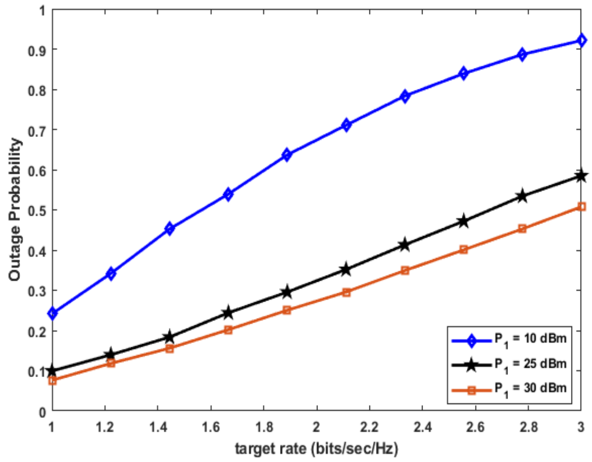

Figure 5. Outage Probability vs. target rate

4. CONCLUSION

An UAV-assisted NOMA-based cellular network has been presented for disaster management in a downlink scenario. The UAV has been utilized for the ground users based on LoS and NLoS in a wide area using a scheduling approach. Also, the NOMA-BS has been used for ground users in a confined area. Eventually, if the user is nearer to UAV, they will communicate to the UAV, but they will communicate to NOMA-BS if the user is not closer to the UAV. Furthermore, if the user is not nearer to UAV or NOMA-BS, they will communicate as a D2D node. The proposed network has estimated the outage probability, coverage probability, and average rate for several network parameters.

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