NOMA Based UAV Relay Communication Protocol in Cellular Network

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***Abstract*—Introducing unmanned aerial vehicles (UAVs) into wireless communication systems has recently gained a lot of attention. UAV provides many advantages such as shorter communication distance and a higher probability of having line-of-sight (LoS) condition due to its dynamic positioning. In this paper, UAV is deployed as a relay station because it can give superior performance due to the high probability of having LoS channel compared to a fixed ground relay station. However, the achievable throughput is decreased as relay communication requires twice of time resources in direct communication. To tackle this problem, non-orthogonal multiple access (NOMA) based communication protocol is proposed in this paper. Furthermore, as a specific problem for UAV, interference from neighbouring base stations (BSs) is large due to LoS channel between UAV and neighbouring BSs. In order to eliminate the interference from neighbouring BSs, UAV relay is equipped with array antenna. The simulation results elucidate that the throughput improvement of the proposed protocol over the conventional protocol.**

I. Introduction

In cellular networks, a base station (BS) located in each cell provides communication services to users within each cell. Since BSs are fixed, the throughput of users located away from BSs decreases due to the increased distance dependent path loss. A relay station (RS) has been considered as a countermeasure to overcome such large attenuation [1]. Since conventional RSs are fixed, they can not flexibly cope with dynamically changing user locations. Therefore, introducing unmanned aerial vehicles (UAVs) equipped with wireless communication functions as RSs has recently gained a lot of attention [2][3][4].

The main advantage of UAV is its dynamic positioning which can be exploited to provide communication services to areas with poor communication infrastructures or to burst traffic due to an event. Besides, since the UAV flies at high altitude, line-of-sight (LoS) links can be established with high probability, which leads to significant channel improvement. On the other hand, relay communication can achieve approximately only half throughput of direct communication because it requires two time slots. Furthermore, interference from neighbouring BSs to the UAV of interest and from neighbouring UAVs to the BS of interest are large because BS-UAV link becomes LoS channel with high probability.

In this paper, a communication protocol considering both uplink (UL) and downlink (DL) is proposed to overcome the throughput degradation of UAV based relay communication. In the proposed protocol, BS transmits the signal to UAV while relay user transmits the signal to the UAV simultaneously by

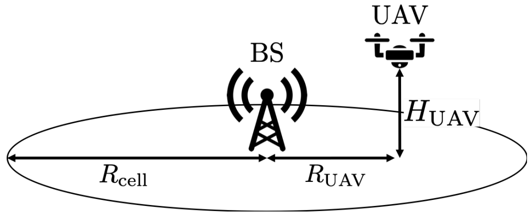


Fig. 1. System model

using the same frequency and time resource. To avoid the interference between BS-UAV communication and UAV-relay user communication, it is required to divide the originally allocated frequency resources. By exploiting the LoS channel between BS and UAV, a power domain non-orthogonal multiple access (NOMA) [8] is applied to enable the relay communication without dividing the frequency resources. To eliminate the interference from neighbouring BSs, the UAV is equipped with an array antenna. To show the throughput improvement brought by the proposed scheme, numerical evaluation is conducted. The numerical results show that the proposed protocol can improve relay user's throughput and is superior to conventional protocol.

The rest of this paper is organized as follows. Section II describes the system model. Section III briefly explains the core technologies of the proposed protocol. Then, the proposed protocol is explained in Section IV. Section V provides computer simulation results. Finally, Section VI concludes this paper.

II. System Model

Consider a cellular network with 19 hexagonal cells and a cell radius is R_{ce} . The center cell is taken as the cell of interest and the remaining cells as the interference cells. Orthogonal frequency division multiple access (OFDMA) is adopted for both DL and UL. The total system bandwidth, B_{tota} [Hz], is equally partitioned into N_{RB} resource blocks (RBs) with bandwidth B_{RB} [Hz] each. J UAVs at altitude H_{UAV} [m] are deployed within each cell with 2D distance R_{UAV} to the cell's BS as shown Fig.1. K users are located randomly and uniformly in an area with a radius of $5R_{\mathrm{ce}}$. Each user is connected to the BS which has the best channel condition to the user. Each user selects the communication protocol by comparing the achievable throughput of direct communication and that of relay communication. Each achiev-

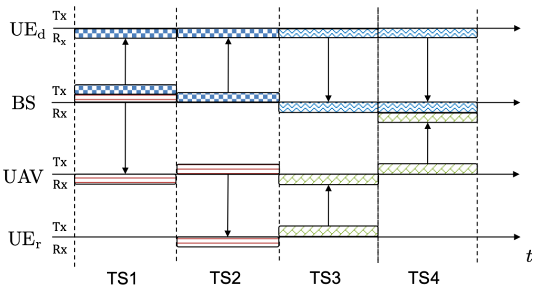


Fig. 2. Conventional protocol

able throughput is calculated by

$$R_{\mathrm{direct}} = B_{\mathrm{RB}} \log\left(1 + \frac{\gamma P}{N_0 B_{\mathrm{RB}}}\right) \quad (1)$$

$$R_{\mathrm{re\ ay}} = \frac{1}{2} B_{\mathrm{RB}} \min\left\{ \log\left(1 + \frac{\gamma_1 P_1}{N B_{\mathrm{RB}}}\right), \log\left(1 + \frac{\gamma_2 P_2}{N_0 B_{\mathrm{RB}}}\right) \right\}, \quad (2)$$

where γ is channel gain between transmitter and receiver and P is the maximum transmission power of the transmitter. In DL case, γ_1 and γ_2 are the channel gain between BS-UAV and UAV-user, P_1 are the maximum transmission powers of the BS. In UL case, γ_1 and γ_2 are the channel gain between user-UAV and UAV-BS, P_2 are the maximum transmission powers of the user. N_0 is one-sided power spectral density of AWGN and minx,y is a function that returns the smaller of x and y.

For simplicity but without loss of generality, let us assume the case of two users. Hereafter, let $\mathrm{UE_d}$ be direct communication user and $\mathrm{UE_r}$ be relay communication user. Fig.2 shows the conventional relay communication protocol. Whole transmission time is divided into multiple time slots (TSs). While $\mathrm{UE_d}$ can receive and transmit two packets in two consecutive TSs, $\mathrm{UE_r}$ receives and transmits only one packet in two TSs. The data rate of $\mathrm{UE_r}$ is given in

$$R_{\mathrm{re\ ay}} = \frac{1}{2} \min\left\{R_1, R_2\right\}, \quad (3)$$

where R_1 is achievable data rate between BS and UAV and R_2 is achievable data rate between UAV and $\mathrm{UE_r}$. Thus, if the same amount of RBs is allocated, the achievable data rate of $\mathrm{UE_r}$ is half of that of $\mathrm{UE_d}$.

A. Channel Models

1) Air-to-Ground Path Loss Model: The air-to-ground channel model is different from terrestrial channel models. The path loss model is given as [5]

$$PL_{\mathrm{AtG}}(r,\theta) = 20\log\left(\frac{4\pi r f_{\mathrm{c}}}{c}\right) + \eta_{\mathrm{LoS}} P(\mathrm{LoS},\theta) + \eta_{\mathrm{NLoS}} P(\mathrm{NloS},\theta), \quad (4)$$

where f_{c} [Hz] is the carrier frequency, c [m/s] is the speed of light, r [m] is the distance between a UAV and a receiver, η_{LoS} and η_{LoS} are average additional losses to the free space propagation for LoS and NLoS connection, respectively, θ [deg] is the elevation angle. $P(\mathrm{LoS},\theta)$ and $P(\mathrm{NLoS},\theta)$ are the probabilities of LoS and NLoS, which are given by

$$\begin{cases} P(\mathrm{LoS},\theta) = \frac{1}{1+a\exp(-b[\theta-a])} \\ P(\mathrm{NLoS},\theta) = 1 - P(\mathrm{LoS},\theta) \end{cases}, \quad (5)$$

where a and b are constant values depending on the environment. This channel model is used for BS-UAV channel and UAV-User channel.

2) BS-to-User path loss model: The path loss model between BS and user is given by [6]

$$PL_{\mathrm{BtU}} = 128.1 + 37.6\log(D), \quad (6)$$

where D [km] is the distance between the BS and the user.

3) User-to-User path loss model: The path loss model between users, which is used to consider interference between users, is [7] given by

$$PL_{\mathrm{UtU}} = 10\alpha\log(d_{\mathrm{uu}}) + 20, \quad (7)$$

where d_{uu} [m] is the distance between users.

III. Existing Technologies

A. Power Domain Non-Orthogonal Multiple Access [8]

In power domain NOMA, a transmitter multiplexes multiple signals and transmits the superposed signal to multiple receivers on the same time & frequency resource. The user with good channel condition performs successive interference cancellation (SIC) to the received signal and removes interfering signals of other users, and then it recovers its own signal. In DL communication, BS selects user 1 with a good channel and allocates small power, then selects user 2 with a worse channel and allocates large power. The transmitted signal is expressed as [8]

$$x = \sqrt{P_1}x_1 + \sqrt{P_2}x_2, \quad (8)$$

where x_i and P_i are the signals and the transmit power to user $i \in \{1,2\}$, respectively. The received signal at user i is given by

$$y_i = h_i x + w_i = h_i\left(\sqrt{P_1}x_1 + \sqrt{P_2}x_2\right) + w_i, \quad (9)$$

where h_i is the complex channel coefficient between BS and user i, and $w_i \sim \mathcal{CN}(0, N_{0,i})$ is additive white Gaussian noise (AWGN) at user i with $N_{0,i}$ being one-sided power spectral density of AWGN. Considering $\gamma_1 > \gamma_2$ ($\gamma_i = |h_i|^2$) gives the following inequality.

$$\underbrace{\log_2\left(1 + \frac{P_2\gamma_1}{P_1\gamma_1 + WN_{0,1}}\right)}_{\triangleq C_{\mathrm{SIC}}} > \log_2\left(1 + \frac{P_2\gamma_2}{P_1\gamma_2 + WN_{0,2}}\right), \quad (10)$$

where W [Hz] is the bandwidth allocated to the users.

Transmit power P_1 and P_2 are assigned so that user 1 can decode x_2. By setting the data rate to user 2 lower than C_2, the signal to user 2 can be correctly decoded at user 1. User

1 with a good channel receives the superimposed signal and decodes the desired signal by performing SIC. Since $\gamma_1 > \gamma_2$ and $P_1 < P_2$, user 1 can decode x_2 without error. Then, x_1 can be extracted by subtracting x_2 from the received signal. User 2 decodes the received signal by treating x_1 as interference. The achievable channel capacity C_1, C_2 of users 1 and 2 are defined as follows.

$$\begin{cases} C_1 = \log_2\left(1 + SINR_1\right) \\ C_2 = \min\left\{\log_2\left(1 + SINR_{\mathrm{SIC}}\right), \log_2\left(1 + SINR_2\right)\right\}, \end{cases} \tag{11}$$

where

$$SINR_1 = \frac{P_1\gamma_1}{WN_{0,1}}, \tag{12}$$

$$SINR_{\mathrm{SIC}} = \frac{P_2\gamma_1}{P_1\gamma_1 + WN_{0,1}}, \tag{13}$$

$$SINR_2 = \frac{P_2\gamma_2}{P_1\gamma_2 + WN_{0,2}}. \tag{14}$$

B. Array Antenna

The channel gain between UAV and BS is generally high due to its high probability of the LoS channel. This is preferable between the UAV and the BS of interest. However, the interference from UAVs in other cells to BS of interest and from BSs in other cells to UAV of interest increase too. Therefore, in this paper, UAV is equipped with a linear array antenna to eliminate the interference from neighbouring BSs.

Let us consider a uniform linear array (ULA) with M antenna elements. First, the wave vector representing the phase fluctuation in the 3D space of the plane wave is defined by

$$\mathbf{k} = \frac{2\pi}{\lambda}[\sin\theta\cos\phi,\ \sin\theta\sin\phi,\ \cos\theta]^T, \tag{15}$$

where θ and ϕ are the elevation and azimuth angle, respectively and λ is wavelength of the desired signal. The steering vector is given by

$$\mathbf{h}(\mathbf{k}) = \sqrt{a}[\exp(-j\mathbf{k}^T\mathbf{r}_0)\cdots\exp(-j\mathbf{k}^T\mathbf{r}_m) \cdots\exp(-j\mathbf{k}^T\mathbf{r}_{M-1})]^T, \tag{16}$$

where $\mathbf{r_m}$ is the vector representing the position of the mth antenna, a is the attenuation factor.

Antenna Weighting by MMSE: The directivity of the array antenna can be steered by controlling the weight for each antenna element. To steer the main beam to a certain direction while the null beam towards the direction of the interference source, we consider the minimum mean square error (MMSE) weight $\mathbf{w}_{\mathrm{MMSE}}$ to minimize the error between the array output and the desired array output. The array input signal is given by

$$\mathbf{y} = s_{\mathrm{d}}\mathbf{h}(\phi_{\mathrm{d}}, \theta_{\mathrm{d}}) + \sum_{i=0}^{I-1} s_i\mathbf{h}(\phi_i, \theta_i) + \mathbf{w}, \tag{17}$$

where s_{d} is the desired signal, s_{i} and $\mathbf{h}(\phi_{\mathrm{i}}, \theta_{\mathrm{i}})$ are the reference signal and the steering vector of the ith interference signal respectively, $\mathbf{w}$ is the noise vector. The array output signal is given by

$$\tilde{y} = \mathbf{w}^H\mathbf{y}. \tag{18}$$

The error between the actual output and the desired output is defined by

$$e = s_{\mathrm{d}} - \tilde{y}. \tag{19}$$

Using this error, the evaluation function J (MSE: Mean Square Error) is given by

$$\begin{aligned} J &= \mathbb{E}\left[ee^*\right] \\ &= \mathbb{E}\left[\left(s_{\mathrm{d}} - \mathbf{w}^H\mathbf{y}\right)\left(s_{\mathrm{d}} - \mathbf{w}^H\mathbf{y}\right)^*\right] \\ &= \mathbf{w}^H\mathbb{E}\left[\mathbf{y}\mathbf{y}^H\right]\mathbf{w} + \mathbb{E}\left[s_{\mathrm{d}}s_{\mathrm{d}}^*\right] - \mathbf{w}^H\mathbb{E}\left[\mathbf{y}s_{\mathrm{d}}^*\right] - \mathbb{E}\left[s_{\mathrm{d}}\mathbf{y}^H\right]\mathbf{w}, \end{aligned} \tag{20}$$

where $\mathbb{E}[\cdot]$ is the expected value operation. The auto-correlation function matrix $\mathbf{R_{yy}}$, signal power σ_{d}^2 and the cross-correlation vector θ of $\mathbf{y}$ and s_{d}^* are respectively given by

$$\begin{cases} \mathbf{R_{yy}} \triangleq \mathbb{E}\left[\mathbf{y}\mathbf{y}^H\right] \\ \sigma_{\mathrm{d}}^2 \triangleq \mathbb{E}\left[s_{\mathrm{d}}s_{\mathrm{d}}^*\right] \\ \boldsymbol{\theta} \triangleq \mathbb{E}\left[\mathbf{y}s_{\mathrm{d}}^*\right]. \end{cases} \tag{21}$$

Substituting (21) into (20) gives

$$J = \mathbf{w}^H\mathbf{R_{yy}}\mathbf{w} + \sigma_d^2 - \mathbf{w}^H\boldsymbol{\theta} + \boldsymbol{\theta}^H\mathbf{w}. \tag{22}$$

(22) results in a convex optimization problem since it is a quadratic program for $\mathbf{w}$. Partial differentiation of (22) with respect to $\mathbf{w}$ gives

$$\nabla J = 2\mathbf{R_{yy}}\mathbf{w} - 2\theta. \tag{23}$$

For $\nabla J = 0$, the weight vector $\mathbf{w}$ can be solved as follows

$$\mathbf{w}_{\mathrm{MMSE}} = \mathbf{R_{yy}}^{-1}\boldsymbol{\theta}. \tag{24}$$

C. Half Wavelength Dipole Antenna

The antenna element being deployed at UAV is half wavelength dipole antenna. The antenna gain is given by [9]:

$$G(\theta, \phi) = 1.641 \times \psi^2\frac{\cos^2(\pi\xi/2)}{\left(1 - \xi^2\right)^2} \tag{25}$$

with

$$\begin{cases} \xi = \sin\theta\cos\phi\sin\alpha + \cos\theta\cos\alpha \\ \psi = \cos\theta\cos\phi\sin\alpha - \sin\theta\cos\alpha, \end{cases} \tag{26}$$

where α is the tilt angle of the half-wavelength dipole antenna.

IV. Proposed Method

A. Communication Protocol

In the conventional protocol, $\mathrm{UE_r}$ keeps silent in TS 1 while BS is transmitting as shown in Fig. 2. On the other hand, in the proposed protocol, BS and $\mathrm{UE_r}$ transmit each signal to UAV by splitting the frequency resource into half as shown in Fig.3. Similarly, in TS2, the UAV sends packets from $\mathrm{UE_r}$ to BS and packets from BS to $\mathrm{UE_r}$. Hence, $\mathrm{UE_r}$ can transmit and receive the amount of signal as $\mathrm{UE_d}$. However, due to the split of frequency resources, the throughput between BS and UAV and that between UAV and $\mathrm{UE_r}$ cannot be increased. In order to overcome this problem, NOMA is introduced by taking advantage of the LoS channel between BS and UAV.

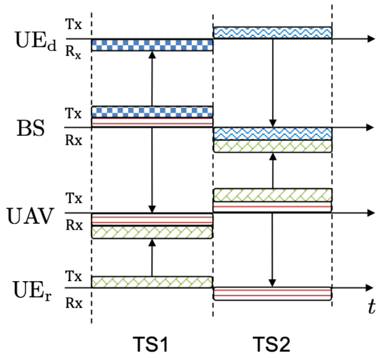


Fig. 3. Proposed protocol

1) TS1: Fig.3 (a) shows how RBs and transmit power are allocated in TS1. BS superimposes the signals to $\mathrm{UE_d}$ and $\mathrm{UE_r}$ on the same RBs. UAV performs SIC to remove the signal to $\mathrm{UE_d}$ and then decodes the signal for $\mathrm{UE_r}$. $\mathrm{UE_d}$ directly decodes its desired signal. At the same time, $\mathrm{UE_r}$ transmits the signal to UAV on the different RBs. The transmit power $P_{\mathrm{BS}\to\mathrm{UAV}}$, for the signal from BS to UAV, is determined as

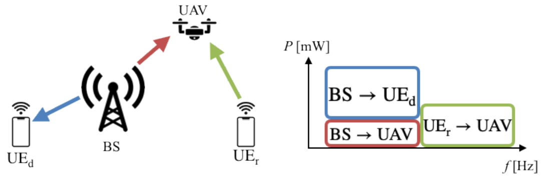
$$P_{\mathrm{BS}\to\mathrm{UAV}} = \min\left(\frac{B_{\mathrm{RB}}N_0 + I_{\mathrm{os,UAV}}}{\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UAV}}}\left(2^{C_\mathrm{m}}-1\right), P_{\mathrm{m,BS}}\right), \tag{27}$$

where C_m[bps/Hz] is the maximum transmission rate, $\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UAV}}$ is the channel gain between BS and UAV, $P_{\mathrm{m,BS}}$ is the maximum transmission power of the BS allocated to one RB and $I_{\mathrm{os,UAV}}$ is an offset which is introduced to prevent the allocated power becoming too small due to the large channel gain. The transmission power $P_{\mathrm{BS}\to\mathrm{UE_d}}$ from the BS to $\mathrm{UE_d}$ is determined by

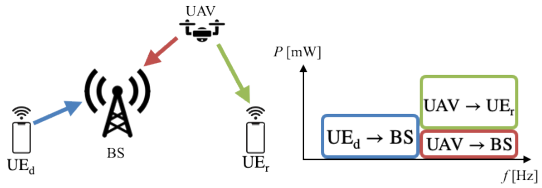
$$P_{\mathrm{BS}\to\mathrm{UE_d}} = \min\left(\left(\frac{B_{\mathrm{RB}}N_0 + I_{\mathrm{os,USER}}}{\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UE_d}}} + P_{\mathrm{BS}\to\mathrm{UAV}}\right)\left(2^{C_m}-1\right), P_{\mathrm{m,BS}} - P_{\mathrm{BS}\to\mathrm{UAV}}\right), \tag{28}$$

where $\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UE_d}}$ is the channel gain between BS and $\mathrm{UE_d}$, $I_{\mathrm{os,USER}}$ is an offset. Without considering the interference offset, the ratio of $P_{\mathrm{BS}\to\mathrm{UAV}}$ and $P_{\mathrm{BS}\to\mathrm{UE_d}}$ will be equal to the ratio of $\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UAV}}$ and $\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UE_d}}$. It can be noticed from (4) and (6) that there is a considerable difference between $\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UAV}}$ and $\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UE_d}}$. Since the transmission power is determined in the same way in the other cells, the signal from other cell's BS to the other cell's $\mathrm{UE_d}$ will be received as interference which considerably reduces the receive SINR at the UAV.

The transmission power $P_{\mathrm{UE_r}\to\mathrm{UAV}}$ from $\mathrm{UE_r}$ to the UAV



(a) Packets flow and allocation of bandwidth, power in STEP1



(b) Packets flow and allocation of bandwidth, power in STEP2

Fig. 4. Packets flow, bandwidth and power allocation in proposed protocol

is determined by

$$P_{\mathrm{UE_r}\to\mathrm{UAV}} = \min\left(\frac{B_{\mathrm{RB}}N_0 + I_{\mathrm{os,BS}}}{\gamma_{\mathrm{UE_r}\leftrightarrow\mathrm{UAV}}}\left(2^{C_\mathrm{m}}-1\right), P_{\mathrm{m,UE_r}}\right), \tag{29}$$

where $I_{\mathrm{os,BS}}$ is an offset, $P_{\mathrm{max,UE_r}}$ is the maximum transmission power of the $\mathrm{UE_r}$ per RB, $\gamma_{\mathrm{UE_r}\leftrightarrow\mathrm{UAV}}$ is the channel gain between UAV and $\mathrm{UE_r}$. The channel capacity $C_{\mathrm{BS}\to\mathrm{UE_d}}$ from BS to $\mathrm{UE_d}$ in STEP 1 is limited to the channel capacity $C_{\mathrm{UAV}}^{\mathrm{SIC}}$ when the UAV performs SIC and is given by

$$C_{\mathrm{BS}\to\mathrm{UE_d}} = \min\left(C_{\mathrm{UAV}}^{\mathrm{SIC}}, C_\mathrm{d}\right), \tag{30}$$

with

$$\begin{cases} C_{\mathrm{UAV}}^{\mathrm{SIC}} = \log_2\left(1 + \dfrac{P_{\mathrm{BS}\to\mathrm{UE_d}}}{P_{\mathrm{BS}\to\mathrm{UAV}} + \frac{I_{\mathrm{UAV}}+B_{\mathrm{RB}}N_0}{\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UAV}}}}\right) \\ C_\mathrm{d} = \log_2\left(1 + \dfrac{P_{\mathrm{BS}\to\mathrm{UE_d}}}{P_{\mathrm{BS}\to\mathrm{UAV}} + \frac{I_{\mathrm{UE_d}}+B_{\mathrm{RB}}N_0}{\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UE_d}}}}\right) \end{cases}, \tag{31}$$

where I_{UAV} and $I_{\mathrm{UE_d}}$ are the interference from the interfering cells (BS, $\mathrm{UE_r}$) to the UAV and $\mathrm{UE_d}$, respectively. Channel capacity $C_{\mathrm{BS}\to\mathrm{UAV}}$ from BS to UAV after performing SIC and channel capacity $C_{\mathrm{UE_r}\to\mathrm{UAV}}$ from $\mathrm{UE_r}$ to UAV are given by

$$\begin{cases} C_{\mathrm{BS}\to\mathrm{UAV}} = \log_2\left(1 + \frac{P_{\mathrm{BS}\to\mathrm{UAV}}\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UAV}}}{B_{\mathrm{RB}}N_0+I_{\mathrm{UAV}}}\right) \\ C_{\mathrm{UE_r}\to\mathrm{UAV}} = \log_2\left(1 + \frac{P_{\mathrm{UE_r}\to\mathrm{UAV}}\gamma_{\mathrm{UAV}\leftrightarrow\mathrm{UE_r}}}{B_{\mathrm{RB}}N_0+I_{\mathrm{UAV}}}\right) \end{cases}. \tag{32}$$

2) TS2: Fig.3 (b) shows how RBs and transmit power are allocated in TS2. UAV superimposes the signals to BS and $\mathrm{UE_r}$ on the same RBs. BS performs SIC to remove the signal to $\mathrm{UE_d}$ and then decodes the signal for $\mathrm{UE_r}$. Since the received signal at the BS from UAV includes the signal sent by the BS to the UAV in TS1, the BS is assumed to be able to perform SIC ideally on the received signal. $\mathrm{UE_r}$ directly decodes its desired signal. At the same time, $\mathrm{UE_d}$ transmits the signal to BS on the different RBs. The transmit power

$P_{\mathrm{UAV}\to\mathrm{BS}}$, for the signal from UAV to BS, is determined as

$$P_{\mathrm{UAV}\to\mathrm{BS}} = \min\left(\frac{B_{\mathrm{RB}}N_0 + I_{\mathrm{os,BS}}}{\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UAV}}}\left(2^{C_{\mathrm{m}}}-1\right), P_{\mathrm{m,UAV}}\right), \tag{33}$$

where $P_{\mathrm{m,UAV}}$ is the maximum transmission power of the UAV allocated to one RB. The transmission power $P_{\mathrm{UAV}\to\mathrm{UE_r}}$ from the UAV to $\mathrm{UE_r}$ is determined by

$$P_{\mathrm{UAV}\to\mathrm{UE_r}} = \min\left(\left(\frac{B_{\mathrm{RB}}N_0 + I_{\mathrm{os,UE_r}}}{\gamma_{\mathrm{UAV}\leftrightarrow\mathrm{UE_r}}} + P_{\mathrm{UAV}\to\mathrm{BS}}\right)\left(2^{C_{\max}}-1\right), P_{\mathrm{m,UAV}} - P_{\mathrm{UAV}\to\mathrm{BS}}\right), \tag{34}$$

where $I_{\mathrm{os,UE_r}}$ is an offset. Meanwhile, the transmission power $P_{\mathrm{UE_d}\to\mathrm{BS}}$ from $\mathrm{UE_d}$ to the BS is determined by

$$P_{\mathrm{UE_d}\to\mathrm{BS}} = \min\left(\frac{B_{\mathrm{RB}}N_0 + I_{\mathrm{os,BS}}}{\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UE_d}}}\left(2^{C_{\mathrm{m}}}-1\right), P_{\mathrm{m,UE_d}}\right), \tag{35}$$

where $P_{\mathrm{m,UE_d}}$ is the maximum transmission power of the $\mathrm{UE_d}$ per RB. The channel capacity from the UAV to the BS after SIC $C_{\mathrm{UAV}\to\mathrm{BS}}$, from the UAV to the $\mathrm{UE_r}$ $C_{\mathrm{UAV}\to\mathrm{UE_r}}$, and from the $\mathrm{UE_d}$ to the BS $C_{\mathrm{UE_d}\to\mathrm{BS}}$ are respectively given by

$$\begin{cases} C_{\mathrm{UAV}\to\mathrm{BS}} = \log_2\left(1 + \frac{P_{\mathrm{UAV}\to\mathrm{BS}}\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UAV}}}{B_{\mathrm{RB}}N_0 + I_{\mathrm{BS}}}\right) \\ C_{\mathrm{UAV}\to\mathrm{UE_r}} = \log_2\left(1 + \frac{P_{\mathrm{UAV}\to\mathrm{UE_r}}}{P_{\mathrm{UAV}\to\mathrm{BS}} + \frac{B_{\mathrm{RB}}N_0 + I_{\mathrm{UE_r}}}{\gamma_{\mathrm{UAV}\leftrightarrow\mathrm{UE_r}}}}\right) \\ C_{\mathrm{UE_d}\to\mathrm{BS}} = \log_2\left(1 + \frac{P_{\mathrm{UE_d}\to\mathrm{BS}}\gamma_{\mathrm{BS}\leftrightarrow\mathrm{UE_d}}}{B_{\mathrm{RB}}N_0 + I_{\mathrm{BS}}}\right), \end{cases} \tag{36}$$

where I_{BS} and $I_{\mathrm{UE_r}}$ are the interference from interfering cells (UAVs, $\mathrm{UE_d}$s) to the BS and the $\mathrm{UE_r}$, respectively.

3) User Pairing: In the proposed protocol, it is necessary to pair two users and categorized as $\mathrm{UE_d}$ and $\mathrm{UE_r}$. The procedure for pairing and categorizing 2 users is described as follows.

(i) Among all the users connected to the BS, select and pair the user with the best channel among $\mathrm{UE_d}$ and the user with the worst channel among $\mathrm{UE_r}$.
(ii) Repeat (i) to the remaining users.
(iii) If some users remain, transmit the signal without using NOMA.

B. Interference Mitigation by Array Antenna

From (32), it can be seen that the UAV receives interference I_{UAV} from interfering cells when it receives the signal from the desired BS in STEP1. Similarly, the BS receives interference I_{BS} from interfering cells when receives a signal from the desired UAV in STEP2. These interferences are needed to be mitigated as the effects are not negligible due to the good channels between BS and UAV. The weight of each antenna mounted on the UAV is calculated with (15) - (24) by dealing the signal from the connecting BS as the desired signal and the signal from the interfering cell's BS as interference. It is assumed that the direction of arrival (DoA) of the interfering BS is known at the UAV. This assumption is reasonable due to the LoS channel between UAV and the BSs.

TABLE I
SIMULATION PARAMETERS

Number of users K	1000
Number of UAVs per BS J	6
Inter cell distance $2R_{\mathrm{cell}}$	1000 [m]
2D distance between BS and UAV R_{UAV}	250 [m]
Carrier frequency f_{c}	2.0 [GHz]
Maximum transmission power of User	13 [dBm]
Maximum transmission power of UAV	13 [dBm]
Maximum transmission power of BS	23 [dBm]
Altitude of UAV H_{UAV}	100 [m]
Altitude of BS	15 [m]
Number of UAV antennas M	4
Antenna tilt angle α	15 [deg]
Noise power density N_0	-174 [dBm/Hz]
$(I_{\mathrm{os,BS}}, I_{\mathrm{os,UAV}}, I_{\mathrm{os,USER}})$	$(-95.0, -80.0, -105.0)$ [dBm]
Coefficients of (4) (a, b)	$(4.88, 0.43)$
Coefficients of (7) α	4.0
$(\eta_{\mathrm{LoS}}, \eta_{\mathrm{NLoS}})$	$(0.1, 21.0)$

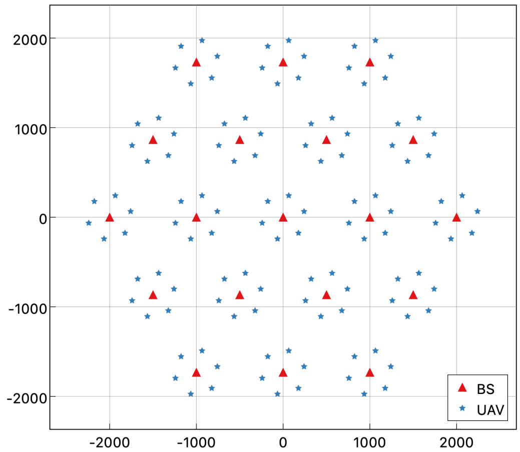


Fig. 5. Position of BSs and UAVs

V. Simulation Results

In this section, the simulation results will be presented. Users are uniformly distributed in an area with a radius of 2500 [m]. The universal frequency reuse is assumed and the total system bandwidth $B_{\mathrm{tota}} = 20$ [MHz] is divided into $N_{\mathrm{RB}} = 100$ RBs. The highest spectrum efficiency is set to $C_{\mathrm{m}} = 6$ [bps/Hz] which is equivalent to 64QAM data modulation. The antenna spacing normalized by the carrier wavelength is set to $\Delta_{\mathrm{n}} = \frac{1}{2}$ to obtain the maximum resolution.

In Fig.6, the cumulative distribution function (CDF) of the sum throughput (DL and UL) of all users connected to the central BS is plotted. The figure shows that the proposed protocol can improve the sum throughput compared to the conventional protocol. This is due to the fact that the proposed protocol avoids using double time slots for relaying by adopting NOMA. However, in the low throughput range ($<$ 1.0 [Mbps]), the conventional protocol exhibits better

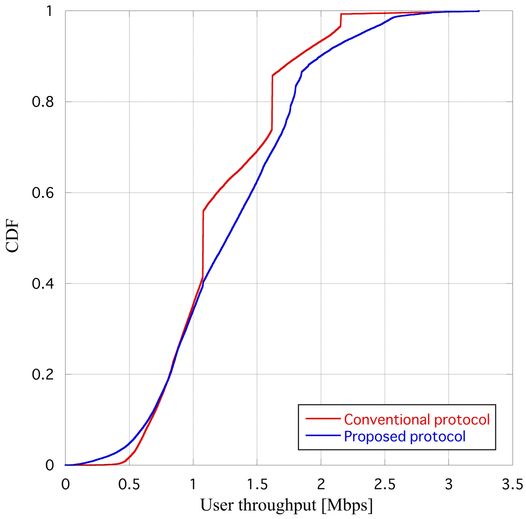


Fig. 6. CDF of user throughput

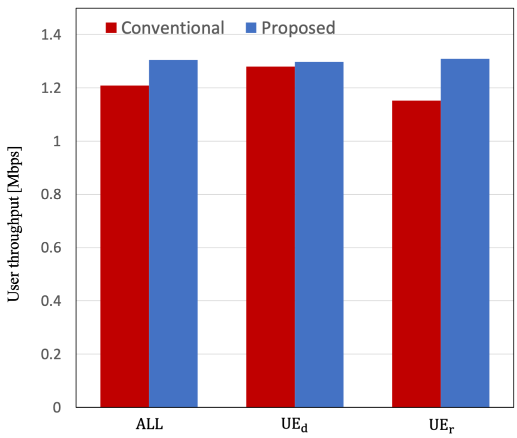


Fig. 7. Average throughput

performance than the proposed protocol. The reason for this can be explained as follows. In the proposed protocol, the transmit power of BS to UAV and $\mathrm{UE_d}$ apt to large since the signal is superposed. Thus, even with the interference mitigation by array antenna at UAV, the interference from neighbouring BSs is still large. Thus, the throughput from $\mathrm{UE_r}$ to UAV is severely degraded. So in spite of interference mitigation by array antenna mounted on UAVs, the interference from interference cell's BSs to UAV becomes large and especially $\mathrm{UE_r}$'s UL throughput in STEP1 degrades. In relay communication, deterioration of either link leads to a decrease in overall throughput as shown in 3.

Fig.7 shows the average throughput of UEs. From this figure, it is clear that the proposed protocol can improve user throughput up to 1.35% for the $\mathrm{UE_d}$, 13.6% for the $\mathrm{UE_r}$ and 7.84% for all users combined.

VI. Conclusion

In this paper, a NOMA based communication protocol for UAV relaying was proposed in order to improve the throughput performance. The proposed protocol takes advantage of good channel condition between BS and UAV. Furthermore, array antenna is equipped at UAV to mitigate the strong interference from neighbouring BSs. Computer simulation results showed that the proposed protocol can increase the user's throughput except for low throughput area (< 1.0 [Mbps]), and improved the all user's average throughput up to 7.84%.

VII. Acknowledgement

A part of this research was conducted by JSPS KAKENHI Grant Number JP18K04127.

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