UAV Beamwidth Design for Ultra-reliable and Low-latency Communications with NOMA

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***Abstract*—In this paper, we investigate the non-orthogonal multiple access (NOMA) based unmanned aerial vehicle (UAV) assisted ultra-reliable and low-latency communications (URLLC) without the presence of base station. To achieve URLLC, we minimize the block error probability by appropriately reducing the beamwidth. Since the user grouping approach can reduce the coverage of user-free area to achieve the beamwidth reduction by only covering the users in each group, we propose two user grouping algorithms for UAV-assisted NOMA transmission. The first one is the improved K-means algorithm. It needs to set the number of groups in advance and has good performance in solving the problem considered in this paper. The second one is an extended affinity propagation (AP) clustering algorithm. This algorithm is easier to implement than the first one because it does not need to pre-define the number of groups, but the performance is inferior to the first algorithm. After user grouping, we introduce a location-based beamwidth design for each group to further minimize the beamwidth and solve the optimization problem. Numerical results show that the performance of the proposed user grouping algorithms with the location-based beamwidth design schemes are superior to the benchmark schemes under the URLLC constraints.**

I. Introduction

The impact of the fifth generation (5G) of cellular mobile communications will completely reshape and change the world. Compared with the fourth generation (4G) of cellular network, to realize the three key 5G scenarios presented by the International Telecommunication Union [1], including the ultra-reliable and low-latency communications (URLLC), enhanced mobile broadband and massive machine-type communication, 5G not only requires to improve the transmission rate, but also pursues the comprehensive improvement of the system performance. For example, the average data rate can be increased by 10 to 100 times; the connection density can be increased by 10 times; and the latency can be reduced to one fifth of that in 4G.

Among the three scenarios of 5G, URLLC is probably the most challenging one, on account of the two mutually exclusive requirements, i.e., ultra reliability and low latency. For URLLC, the ultra-high reliability in terms of block error probability may be as low as 10^{-5} or even 10^{-9} within the latency of 1 millisecond. In order to satisfy the constraints of URLLC, the finite blocklength is widely used [2]–[4]. Generally speaking, the representative applications of 5G URLLC are the internet of vehicles, unmanned aerial vehicle (UAV) networks, etc. The 4G networks can meet some of the low sum-rate and latency-insensitive UAV applications, but pose challenges for ultra low-latency UAV applications. As 5G URLLC can meet the requirements for most of the UAV applications, it is worthy to be studied.

In order to enable users to be served by the same UAV at the same time, users within a specific coverage need to share a certain communication bandwidth, where the orthogonal multiple access (OMA) is not efficient enough. The non-orthogonal multiple access (NOMA) technology being capable of sharing spectrum with multiple users is utilized to improve spectral efficiency. Recently, the NOMA-based UAV-assisted communication networks have been discussed in many literature [5]–[7]. A general multiple-input multiple-output (MIMO) NOMA UAV-aided network is proposed in [5], and the sum-rate and outage performance are analyzed. The authors in [6] further consider the physical limitations of the antenna array, and introduce the beam scanning to enhance the sum-rate performance in UAV-assisted network. The multi-antenna UAV-aided network with limited feedback of NOMA is proposed in [7] to obtain the full channel state information, which can improve the sum-rate performance. According to the research, it is worth noting that the URLLC for UAV-assisted NOMA transmission is rarely considered in the prior works. Furthermore, compared with the traditional wireless communications, UAV-assisted wireless communications can provide ubiquitous coverage without the presence of ground infrastructures, and can achieve high sum-rate for the dominate line-of-sight (LoS) connection with the ground user. To fully exploit the characteristics of UAV, it is crucial to optimize the UAV parameters. The problems for optimizing the altitude, beamwidth and location for UAV-assisted multi-user communications are proposed in [8], [9]. However, when optimizing beamwidth, the pointing direction of the beam is generally perpendicular to the ground, which is not efficient enough for sparsely distributed users.

In this paper, we investigate the URLLC of UAV-assisted NOMA transmission scheme. The main contributions are summarized as follows:

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1) This paper investigates the UAV-assisted NOMA transmisson for URLLC with finite blocklength. Under the URLLC constraints, the beamwidth and number of groups are jointly optimized to minimize the block error probability subject to the latency constraint. It should be pointed that the NOMA transmission is presented for multiple users, not limited to the two-user case.
2) To solve the observed problem, the coverage of user-free area needs to be reduced to minimize the beamwidth under the restriction of the number of groups, which can achieve the low block error probability. In this case, we divide users into different groups so that the UAV beam only needs to cover the users in each group, which can sufficiently reduce the coverage of user-free area. In this regard, we introduce two user grouping algorithms. The first one has good performance but needs to pre-set the number of groups. The second one is easier to implement but the performance is inferior to the first algorithm.
3) For each user grouping scheme, we design the coverage area according to the users' locations. Based on the coverage area, a location-based beamwidth design is proposed, in which the beam pointing direction is adjusted to the users' locations.

II. System Model

Consider the downlink UAV-terrestrial communication network in a circular area with radius R. The total K users that are ramdomly distributed in the observed area will be divided into S groups. The number of users in the s-th group is denoted as K_s with $\sum_{s=1}^{S} K_s = K$. In the network, the UAV is deployed directly above the center of the area with altitude H, and adopts NOMA transmission to the users belonging to each group. Due to the low transmission period, the UAV position can be regarded as unchanged. According to [10], the channel between the UAV and user is dominated by LoS propogation, and the non-LoS (NLoS) component is relative small that can be ignored. We assume that the users' locations can be obtained in advance by Global Position System (GPS), and due to the user's low moving speed, the changes of user location are not taken into consideration. For simplicity, the coordinate of the UAV with horizontal, vertical location and altitude H is given as $[x_0, y_0, H]$, and the coordinate of the user i in group $s = 1, \ldots, S$ with horizontal and vertical location is denoted as $[x_i^s, y_i^s, 0]$, $i = 1, \ldots, K_s$. Sort the users in group s in the descending order of $d_i^s = \sqrt{|x_i^s - x_0|^2 + |y_i^s - y_0|^2}$ as $d_1^s \geq \ldots \geq d_{K_s}^s$. The channel gain between the UAV and user i in group s is

$$h_i^s = \frac{\varrho_0}{\sqrt{(d_i^s)^2 + H^2}^{\frac{\xi}{2}}}, \tag{1}$$

where ϱ_0 is the reference channel gain for the distance equal to 1 m, and ξ is the path loss exponent.

The elevation and azimuth half-power beamwidths of 3-D UAV beam are denoted as $2\Theta_1$ and $2\Theta_2 \in (0, \pi)$, respectively. From [11], the antenna gain in the direction with elevation angle ϑ and azimuth angle φ can be summarized as

$$G = \begin{cases} \frac{G_0}{\Theta_1 \Theta_2} & \text{if } 0 \leq \vartheta \leq \Theta_1 \text{ and } 0 \leq \varphi \leq \Theta_2, \\ g & \text{otherwise}, \end{cases} \tag{2}$$

where $G_0 \approx 2.2846$ and g is the sidelobe gain.

A. Multiuser NOMA Transmission

In general, for the K_s-user NOMA transmission, the signal-to-interference-plus-noise ratio (SINR) of user i ($i = 1, \ldots K_s$) in group s is given as

$$\begin{aligned} \gamma_i^s &= \begin{cases} \frac{\frac{P_u}{\sigma^2} G h_i^s \alpha_i}{\frac{P_u}{\sigma^2} G h_i^s \sum_{m=i+1}^{K_s} \alpha_m + 1} & i = 1, \ldots, K_s - 1, \\ \frac{P_u}{\sigma^2} G h_i^s \alpha_i & i = K_s, \end{cases} \\ &= \begin{cases} \frac{A_i}{D_i + \Theta_1^s \Theta_2^s \sqrt{\left(d_i^s\right)^2 + H^2}^{\frac{\xi}{2}}} & i = 1, \ldots, K_s - 1, \\ \frac{A_i}{\Theta_1^s \Theta_2^s \sqrt{\left(d_i^s\right)^2 + H^2}^{\frac{\xi}{2}}} & i = K_s, \end{cases} \end{aligned} \tag{3}$$

where $A_i = \frac{P_u}{\sigma^2} G_0 \varrho_0 \alpha_i$; $D_i = \frac{P_u}{\sigma^2} G_0 \varrho_0 \sum_{m=i+1}^{K_s} \alpha_m$; α_i is the power allocation factor of user i satisfying $\alpha_1 > \alpha_2 > \ldots > \alpha_{K_s}$ and $\sum_{i=1}^{K_s} \alpha_i = 1$; P_u is the total transmitted power of UAV; and σ^2 denotes the power of the additive white Gaussian noise (AWGN).

B. Optimization Problem

In URLLC, due to the low transmission latency, the blocklength needs to be rather short. Therefore, we adopt the finite blocklength for NOMA transmission. Assume that the bandwidth is B. When transmitting N bits, the end-to-end latency consists of the transmission latency τ_t, the backhaul latency τ_b and the queuing latency τ_q. As the optimization of τ_b and τ_q have been discussed in [12], the optimization of these two parameters are not the scope of this paper, and can be directly used. The block error probability ε_i^s for user i in group s is given as

$$\varepsilon_i^s = Q\left(\frac{\frac{1}{S}\tau_t B \ln\left(1 + \gamma_i^s\right) - N \ln 2}{\sqrt{\frac{\frac{1}{S}\tau_t B \gamma_i^s \left(2 + \gamma_i^s\right)}{\left(1 + \gamma_i^s\right)^2}}}\right). \tag{4}$$

The reliability of the entire network is denoted as

$$P_{\text{reliable}} = \prod_{s=1}^{S} \left(\prod_{i=1}^{K_s} \left(1 - \varepsilon_i^s\right)\right). \tag{5}$$

For a pre-defined latency constraint, the block error probability needs to be minimized to achieve the ultra-reliable transmission. From (4), the optimization problem can be expressed as

$$\begin{aligned}
&\min_{\Theta_1^s,\Theta_2^s,S} \ \varepsilon_i^s \\
&\text{s.t. } C1: \ \log(1+\gamma_{th}) \geq \tfrac{(K-2(S-1))NS}{\tau_t B}, \\
&\quad\ C2: \ \gamma_i^s \geq \gamma_{th}, \\
&\quad\ C3: \ \Theta_{\min} \leq \Theta_1^s \leq \Theta_{\max}, \\
&\quad\ C4: \ \Theta_{\min} \leq \Theta_2^s \leq \Theta_{\max},
\end{aligned} \tag{6}$$

where γ_{th} is the SINR threshold. The above problem is actually supposed to maximize the reliability of the system, but the optimization problem is difficult to solve. When the users' locations can be known in advance by GPS, we take a step back here to minimize the block error probability for each user to ensure the reliability of the system. In this case, we solve the optimization problem by two steps. In the first step, we consider the above problem with given S. In this case, we define the function

$$f(x) = \frac{\sqrt{u}\ln(1+x) - v}{\sqrt{\frac{x(2+x)}{(1+x)^2}}}, \tag{7}$$

and the first-order derivative of this function is given as

$$\begin{aligned}
f'(x) &= \frac{\frac{\sqrt{u}}{1+x}\sqrt{\frac{x(2+x)}{(1+x)^2}} - \sqrt{\frac{1}{x(2+x)}}\frac{1}{(1+x)^2}\left(\sqrt{u}\ln(1+x)-v\right)}{\frac{x(2+x)}{(1+x)^2}} \\
&= \sqrt{\frac{u}{x(2+x)}}\left(1 - \frac{1}{(x+2)\sqrt{x^3}}\left(\ln(1+x) - \frac{v}{\sqrt{u}}\right)\right).
\end{aligned} \tag{8}$$

When $C2$ in (6) is satisfied, we have $f'(x) > 0$, and $f(x)$ is an increasing function. As Q-function is monotonically decreasing, the optimization problem can be simplified as

$$\begin{aligned}
&\max_{\Theta_1,\Theta_2} \quad \gamma_i^s \\
&\text{s.t.} \quad C2 - C4.
\end{aligned} \tag{9}$$

As the problem (9) is convex, we investigate a two-stage approach to solve it. In the first stage, denoting Θ_1^{s*} as the optimal value of Θ_1^s, the objective function is an decreasing function in Θ_1^s with given Θ_2^s. We declare that Θ_1^{s*} is the minimum value of Θ_1^s. In the second stage, for the optimal value Θ_1^{s*}, the objective function is an decreasing function in Θ_2^s with given Θ_1^{s*}. Therefore, the optimal solution of the problem (9) is to find the minimum values of the elevation and azimuth half-power beamwidths.

As the objective function is increasing in S with the fixed γ_i^s and the large S can result in the large γ_i^s, we need to find the appropriate value of S. Therefore, in the second step, we need to determine the appropriate value of S with $C1$.

III. User Grouping Algorithm and Beamwidth Design

For URLLC transmission, the block error probability needs to be minimized to 10^{-5} or even 10^{-9} when the latency is lower than 1ms. From the above derivations, in order to ensure that the UAV beam can effectively cover the desired users while reducing the beamwidth for the NOMA transmission, we divide the users into several groups to reduce the coverage of the user-free area and the UAV can serve different groups during different time periods. Two user grouping algorithms that suitable for UAV-assisted NOMA transmission in URLLC are proposed in this section. Meanwhile, the coverage area is designed for each group. Based on the coverage area of each group, we introduce the location-based beamwidth design, in which the beam pointing direction is adjusted to the users' locations.

A. Improved K-means Algorithm for NOMA transmission

The K-means algorithm is an iterative process. The typical distance-based K-means algorithm uses the distance as the similarity metric, which can provide an efficient approach when the number of groups is set properly in advance. However, when the traditional K-means algorithm is adopted, there may exist a case that one group only has one user. To ensure that the users in one group can share resources and adopt NOMA transmission to improve the spectrum efficiency, an improved K-means algorithm is proposed based on the traditional K-means algorithm, as presented in Algorithm 1.

B. Extended Affinity Propagation (AP) Clustering Algorithm

Although the K-means algorithm can perform user grouping well, it is still necessary to design the number of groups in advance. Compared with K-means, AP clustering algorithm is easy to implement because it does not need to pre-define the number of groups, and the center of each group is an actual user point rather than the average value between multiple user points as in K-means. Generally, in AP clustering algorithm, we represent the similarity matrix as $\mathfrak{S}$, which consists of the negative distances between any two users, shown as

$$\mathfrak{s}(i,k) = -\left(\|x_i - x_k\|^2 + \|y_i - y_k\|^2\right). \tag{10}$$

In each iteration, two types of messages are necessary in the AP clustering algorithm, i.e., 'responsibility' and 'availability'. Matrix of 'responsibility' $\mathfrak{R}$ has element $r(i,k)$ to represent the degree of whether user k is appropriate to be served as the group center of user i. Matrix of 'availability' $\mathfrak{A}$ has element $a(i,k)$ to represent the suitable degree of user i choosing user k as the group center. The 'preference' of user i is denoted as $p(i)$ to represent the reference degree of user i being served as the group center, and contains in the 'preference' matrix $\mathfrak{P}$. The 'preference' generally takes the median of similarity $\mathfrak{S}$. In iteration t, $r_{t+1}(i,k)$ and $a_{t+1}(i,k)$ for the next iteration are expressed in (11) and (12), where (12) is shown in the top of the next page.

$$r_{t+1}(i,k) = \begin{cases} \mathfrak{s}(i,k) - \max\limits_{j\neq k}\{a_t(i,j) + r_t(i,j)\} & i \neq k, \\ \mathfrak{s}(i,k) - \max\limits_{j\neq k}\{\mathfrak{s}(i,j)\} & i = k, \end{cases} \tag{11}$$

Besides, there also exists the damping factor λ for convergence. Based on the general AP clustering algorithm, the extended AP clustering algorithm is shown in Algorithm 2.

Algorithm 1 The improve K-means algorithm for UAV-assisted NOMA transmission

Input: The coordinates of all users, and the pre-defined number of groups S

Output: Actual number of groups S_a, and several groups of users G_s for $s = 1, \ldots, S_a$

1) Choose S users as the initial group centers.
2) Calculate the distances between other users to the choosen group centers.
3) The users are arranged to S groups corresponding to their nearest grouping center based on the nearest distance criterion.
4) Update the group centers: Use the mean value of all user locations in each group as the new group center.
5) Repeat steps 2-4 until the group center no longer changes.
6) **for** $s = 1, \ldots, S$
7)   **if** $\mathrm{isempty}(G_s)$
8)   Delete the empty group.
9) $S = S - 1$.
10)   **end**
11)   **if** $size(G_s, 1)$==1
12)   Select a user i, who is closest to the single user in group s.
13)   Find which group the user i belongs to and set the group index as $j \neq s$.
14)   **if** $size(G_j, 1) > 2$
15)   Delete user i from G_j and add user i to G_s.
16)   **else**
17)   Add the user in G_s to G_j and delete G_s.
18) $S = S - 1$.
19)   **end**
20)   **end**
21) $S_a = S$.
22) **end**

C. Coverage Area and Beamwidth Design

For each group, we design the coverage area to cover all users based on the users' locations. The elevation and azimuth half-power beamwidths are also derived for each group according to the designed coverage area. As shown in Fig. 1, for the location-based beamwidth design, we recommend that the beam pointing direction is adjusted to users' locations and the elevation and azimuth half-power beamwidths do not have to be equal.

The center and radius of the coverage area should be derived at first. Let $x^s_{max} = \max_{i=1,\ldots,K_s} x^s_i$, $x^s_{min} = \min_{i=1,\ldots,K_s} x^s_i$, $y^s_{max} = \max_{i=1,\ldots,K_s} y^s_i$ and $y^s_{min} = \min_{i=1,\ldots,K_s} y^s_i$. The center of the small area $\left(\frac{x^s_{max}+x^s_{min}}{2},\, \frac{y^s_{max}+y^s_{min}}{2},\, 0\right)$ is marked as $(x^s_c,\, y^s_c,\, 0)$ and the radius is $r_s = \frac{1}{2}\sqrt{\left(x^s_{max} - x^s_{min}\right)^2 + \left(y^s_{max} - y^s_{min}\right)^2}$. From Fig. 1, the beamwidths for Θ^s_1 and Θ^s_2 are denoted as

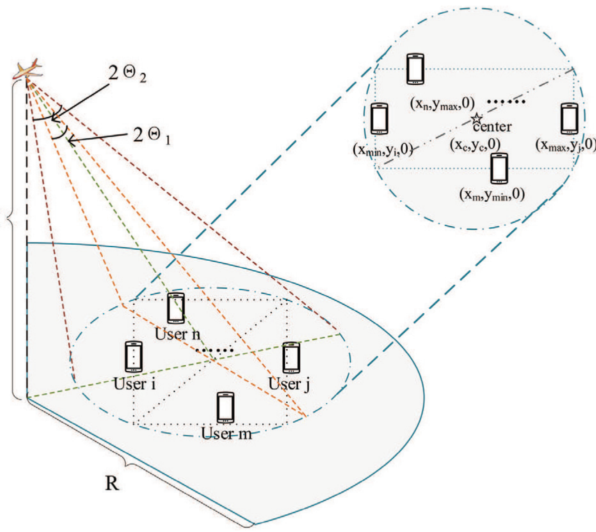

Fig. 1. Coverage area design

$$\Theta^s_1 = \arctan\sqrt{\frac{r^2_s}{d^2_c + H^2}}, \tag{13}$$

$$\Theta^s_2 = \tfrac{1}{2}\arctan\left(\tfrac{d_c+r_s}{H}\right) - \tfrac{1}{2}\arctan\left(\tfrac{d_c-r_s}{H}\right), \tag{14}$$

where $d_c = \sqrt{\left(x^s_c\right)^2 + \left(y^s_c\right)^2}$.

Furthermore, we need to ensure that all the users in each group are within the beam coverage area at first, and the optimization problem (9) can be formulated as

$$\begin{aligned}
&\min_{\Theta^s_1,\Theta^s_2}\ \gamma^s_i\\
&s.t.\ C1:\ \gamma^s_i \geq \gamma_{th},\\
&\quad C2:\ \tan^2\Theta^s_1 \geq \tfrac{(x^s_c-x^s_i)^2+(y^s_c-y^s_i)^2}{d^2_c+H^2},\\
&\quad C3:\ 2\Theta^s_2 \geq \arctan\left(\tfrac{d_c+\sqrt{\left(x^s_c-x^s_i\right)^2+\left(y^s_c-y^s_i\right)^2}}{H}\right) -\\
&\qquad\qquad \arctan\left(\tfrac{d_c-\sqrt{\left(x^s_c-x^s_i\right)^2+\left(y^s_c-y^s_i\right)^2}}{H}\right),\\
&\quad C4:\ \Theta_{\min} \leq \Theta^s_1 \leq \Theta_{\max},\\
&\quad C5:\ \Theta_{\min} \leq \Theta^s_2 \leq \Theta_{\max}.
\end{aligned} \tag{15}$$

Denote $(\Theta^{s*}_1,\, \Theta^{s*}_2)$ as the optimal solution of the problem (15). From Fig. 1, Θ^{s*}_1 and Θ^{s*}_2 for each group can be expressed as

$$\Theta^{s*}_1 = \max\left\{\ \Theta_{\min},\quad \arctan\sqrt{\tfrac{r^2_s}{d^2_c+H^2}}\ \right\}, \tag{16}$$

$$\Theta^{s*}_2 = \max\left\{\Theta_{\min},\, \tfrac{1}{2}\left(\arctan\left(\tfrac{d_c+r_s}{H}\right) - \arctan\left(\tfrac{d_c-r_s}{H}\right)\right)\right\}. \tag{17}$$

This declaration can be proved by contradiction approach. If $(\Theta^s_1,\, \Theta^s_2)$ is the optimal solution of the optimization problem with $\Theta^s_1 > \Theta^{s*}_1$ and $\Theta^s_2 > \Theta^{s*}_2$, we can obtain

$$a_{t+1}(i,k) = \begin{cases} \min\left\{0,\ r_{t+1}(k,k) + \sum\limits_{j\neq i,k} \max\left\{r_{t+1}(j,k),0\right\}\right\} & i \neq k, \\ \sum\limits_{j\neq k} \max\left\{r_{t+1}(j,k)\,,\ 0\right\} & i = k, \end{cases} \tag{12}$$

Algorithm 2 The extended AP clustering algorithm for UAV-assisted NOMA transmission

Input: The coordinates of all users, similarity matrix $\mathfrak{S}$, 'preference' matrix $\mathfrak{P}$ and total iteration times t_0

Output: The number of groups S_a, and several groups of users G_s for $s = 1, \ldots, S_a$

1) Initialize the 'responsibility' matrix $\mathfrak{R}$, 'availability' matrix $\mathfrak{A}$ and iteration t to zero.
2) **while** $t \leq t_0$ **do**
3) Calculate the 'responsibility' and 'availability' by (11) and (12).
4) To avoid oscillations, we introduce the damping factor $\lambda \in (0,\,1)$ when updating the 'responsibility' and 'availability'. Hence, we have
$r_{t+1}(i,k) = \lambda r_t(i,k) + (1-\lambda)\, r_{t+1}(i,k)$
$a_{t+1}(i,k) = \lambda a_t(i,k) + (1-\lambda)\, a_{t+1}(i,k)$
5) $t = t + 1$
6) Determine the group center by
$S = \arg\max\left\{a(i,k) + r(i,k)\right\}$.
7) **until** converge
8) Step 6)-22) in Algorithm 1.

$\frac{A}{B+\Theta_1^{s*}\Theta_2^{s*}\left(\left(d_i^s\right)^2+H^2\right)} > \frac{A}{B+\Theta_1^{s}\Theta_2^{s}\left(\left(d_i^s\right)^2+H^2\right)}$, which is contrary to the optimization objective. Therefore, we prove that $(\Theta_1^{s*},\ \Theta_2^{s*})$ is the optimal solution.

IV. Numerical Results

In this section, we present the simulation results to demonstrate the performance of the two algorithms with the location-based beamwidth design we proposed. We utilize the beamwidth optimization approach in [8] and the algorithms in [13], [14] as the benchmarks. The power allocation factors are arithmetic decrements and the sum of them is one in each group. The threshold of SINR is set to 0.2 and the number of groups is taken as 3 according to the parameters in this paper. The transmit signal-to-noise ratio (SNR) is represented by $\frac{P_u}{\sigma^2}$. Other simulation parameters are listed in Table 1.

In Fig. 2, under URLLC restrictions, we consider the block error probability versus the transmit SNR with the total latency less than $1\,\mathrm{ms}$. According to the above formulas, the number of groups can affect the block error probability. The performance obtained from the large number of groups may not be better than that from the small number of groups. Despite the AP clustering algorithm does not need to pre-set the number of groups, the overall performance may degrade due to the large number of groups. Therefore, although the K-means algorithm needs to determine the number of groups in advance, its performance is superior to the AP clustering algorithm in this paper. Furthermore, under the UAV-assisted NOMA transmission, it is observed that the proposed two algorithms with location-based beamwidth design outperform the benchmarks. Besides, when the transmit SNR is large, the transmission reliability is improved extremely, which can sufficiently meet the URLLC transmission requirement.

Fig. 3 shows the trade-off between the overall block error probability and the transmission latency when the transmit SNR is equal to $40\,\mathrm{dB}$. It is observed that the proposed user grouping algorithms with beamwidth design can achieve the ultra-reliable transmission in a low latency constraint, which satisfies the NOMA-based UAV-assisted URLLC restrictions.

Table I
Simulation Parameters

Parameters	Values
Radius R	$30\,\mathrm{m}$
Number of users K	10
Height H	$30\,\mathrm{m}$
G_0	2.2846
Reference channel gain ϱ_0	1.42×10^{-4}
Total latency τ	$1\,\mathrm{ms}$
Transmission latency τ_t	$0.1\,\mathrm{ms}$
Minimal beamwidth $2\Theta_{\min}$	0
Maximal beamwidth $2\Theta_{\max}$	π
Bandwidth B	200 MHz
Transmision bits N	20 bytes
Backhaul latency τ_b	$0.1\,\mathrm{ms}$
Queuing latency τ_q	$0.8\,\mathrm{ms}$
Path loss exponent ξ	2
Sidelobe gain g	0
Damping factor λ	0.9
Total iteration times t_0	10^4

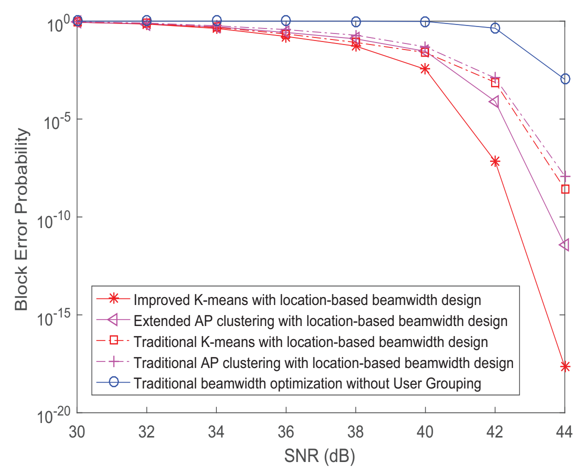

Fig. 2. The total block error probability versus the transmit SNR

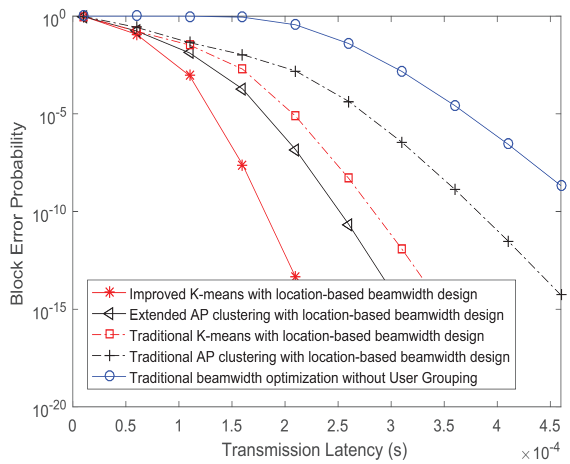

Fig. 3. The block error probability versus the transmission latency

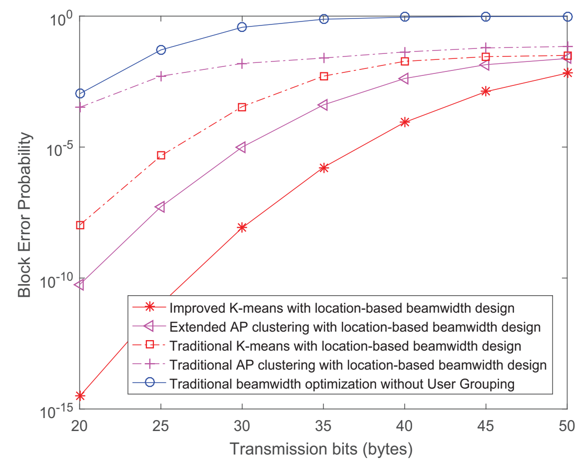

Fig. 4. The block error probability versus the number of transmission bits

The reason for this result is that the conventional UAV-assisted transmissions have the beam pointing direction perpendicular to the ground. When the users are sparsely distributed, the general methods cover a large user-free area and result in the large beamwidth. According to the optimization objective in this paper, it is necessary to find the minimum beamwidth. While the proposed user grouping algorithms with the location-based beamwidth design can sufficiently reduce the coverage of user-free area and effectively minimize the beamwidth. Therefore, the proposed schemes in this paper are superior to other benchmark schemes.

In Fig. 4, the block error probability versus different transmission bits is discussed. In URLLC, owing to the low-latency requirement, we use the finite blocklength for UAV-assisted NOMA transmission. Therefore, for a given transmission latency, the relationship between the block error probability and the transmission bits is worth discussing. As shown in Fig. 4, the block error probability increases as the number of transmission bits grows. For a large number of transmission bits, in a given short duration, the block error probability becomes large and results in the poor reliability. Anyway, the proposed schemes outperform the compared schemes.

V. Conclusions

In this paper, we present a UAV-assisted NOMA transmission under URLLC constraints. We jointly optimize the number of groups and beamwidth to minimize the block error probability. To solve the problem, the coverage of user-free area needs to be reduced to minimize the beamwidth under the restriction of the number of groups. In this regard, we propose the improved K-means and extended AP clustering algorithms, which divide users into several groups to guarantee the reduction of user-free coverage area. Furthermore, based on each group, we introduce a location-based beamwidth design to further minimize the UAV beamwidth and realize the NOMA-based URLLC transmisson. Numerical results present that the proposed user grouping algorithms with location-based beamwidth design are superior to other benchmarks, and guarantee the requirements of NOMA-based UAV-assisted URLLC transmission.

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