Abstract—Millimeter-wave (mm-wave) communication is a promising technology for supporting extremely high data rates in the next generation wireless networks. Mm-wave signals experience high path loss and directional transmission is required to compensate the severe channel attenuation. The special characteristics of the mm-wave propagation arise opportunities as well as challenges for the network resource allocation problems. In this paper, a fair user association, beamwidth selection and power allocation problem for indoor mm-wave networks is studied. The objective of the optimization problem is to maximize the minimum user throughput to provide a fair resource distribution among the users. In our model, we take into account the unique mm-wave communications features, namely beam alignment procedure and directional transmission. Simulation results confirm the superior performance of the proposed solution compared to the existing approaches.

I. INTRODUCTION

To accommodate the growing surge of high data rates in wireless communication networks, the system capacity has been enhanced using advanced modulation and signal processing techniques. Nonetheless, the efficiency of these schemes is restricted because of the narrow bandwidth of the legacy networks. Hence, the millimeter-wave (mm-wave) technology is a promising choice to abate the imminent spectrum scarcity and boost the network capacity. In this respect, there is an increasing effort devoted to the area of the mm-wave communications. However, there are some technical challenges in the development of communication networks based on the mm-wave technology. The channel path loss in the mm-wave bands is generally higher than that of traditional microwave frequencies. Moreover, due to inherent propagation characteristics, mm-wave signals are more sensitive to blockage compared to the conventional bands. Furthermore, the immense amount of available bandwidth leads to significantly higher accumulated noise power at the receiver. Nevertheless, the small wavelength at the mm-wave bands allows the implementation of vast number of antenna elements in the current size network devices. Thus, beamforming techniques are adopted to overcome the severe path loss. Directional transmission is also beneficial for reducing the interference level. To fully exploit the directivity gain, transmitter and receiver beams should be carefully aligned. To this end, in the recent IEEE standards [1] and [2], firstly a sector-level sweep is performed, followed by the beam-level searching process. The beam training procedure incurs an alignment overhead, which depends on the operating beamwidths, and this affects the resource allocation policy.

There are several studies in the literature that scrutinize directional transmission in mm-wave communications. A concurrent beamforming protocol for optimally exploiting the directionality in mm-wave networks is presented in [3]. Authors in [4] address the joint beam searching and transmission scheduling problem to further improve spatial resource reuse. Moreover, a standard-compliant protocol for the interference-aware scenario is introduced. In [5], joint association control and relay selection problem in mm-wave network is formulated as an optimization problem. Then, a distributed auction-based solution is presented for the multi-assignment class problem. The authors in [6] discuss the key MAC layer issues in cellular networks, such as random access procedures, frequent handover, scheduling and user association problems.

In this paper, we study the problem of user association, beamwidth selection and power allocation for an indoor mm-wave network. We first capture the interaction between the beam-alignment overhead and the achievable throughput of a mm-wave communication link. Then, we formulate the beamwidth selection and resource allocation as an optimization problem. The target of the considered problem is to maximize the minimum user throughput to attain a fair solution and provide a uniform QoS guarantee throughout the network. The considered problem is combinatorial and non-convex. Regarding the special mm-wave communication features, namely directional transmissions and limited ability to support different transmit beams, a low-complexity algorithm for the user association and beamwidth selection is presented. Then, the power allocation problem is solved using primal-dual subgradient method. Finally, the simulation results demonstrate the superiority of the proposed scheme to the adopted approach in the existing mm-wave standards.

The remainder of the paper is organized as follows. In Section II, the network model and beam alignment procedure are described. In Section III, the problem is formulated as an optimization problem and the solution approach is proposed. Simulation results and remarks are presented in Section IV and conclusion is drawn in Section V.

II. SYSTEM MODEL AND SCENARIO DESCRIPTION

Consider an indoor mm-wave network consisting of a set of access points (APs), \( \mathcal{N} = \{1, \ldots, N\} \), and a set of wireless...
where $P$ is restricted to Moreover, since the total transmit power of each transmitter device, and hence the number of supported user devices by beams. Besides, each transmit beam is directed towards a user beam, each AP can support a limited number of transmit beams. Therefore, the beamforming techniques are exploited to combat the severe path loss. It should be noted that since a specific frequency, the overall time duration of the alignment phase between AP $i$ and user $k$, denoted by $\tau_{ik}$, can be expressed by

$$\tau_{ik} = T_p \frac{\psi_{ik}^u}{\phi_{ik}^u \phi_{ik}^n},$$

where $\phi_{ik}^u$ and $\phi_{ik}^n$ are, respectively, the beamwidth of the user $k$, and the beamwidth of AP $i$ for data transmission to user $k$. Moreover, $\psi$ indicates the sector-level beamwidths, and for simplicity, we use superscript $a$ to specify parameters related to APs and $u$ for user devices. Upon accomplishment

Fig. 1. An example of a mm-wave wireless network.
of the beam alignment procedure, the optimal directions for data transmission and reception are discovered and the mm-wave communication link can be established to start the data transmission phase. Note that the alignment time duration cannot surpass the time slot duration $T$, and thus the feasible region is constrained by

$$a_{ik}\psi^a\psi^u \frac{T_p}{T} \leq \phi^a_{ik} \phi^u_k, \quad \forall i \in \mathcal{N}, \forall k \in \mathcal{M}. \quad (6)$$

Furthermore, because the beam alignment occurs within the sector-level beamwidths, we have

$$\phi^a_{\min} \leq \phi^a_k \leq \psi^u, \quad \forall k \in \mathcal{M}, \quad (7)$$

$$a_{ik}\phi^a_{\min} \leq \phi^a_{ik} \leq a_{ik}\psi^u, \quad \forall k \in \mathcal{M}, \forall i \in \mathcal{N}, \quad (8)$$

where $\phi^a_{\min}$ and $\phi^a_{\min}$ are the minimum possible operating beamwidth for user devices and APs, and they depend on the number of antenna elements implemented in the devices and the antenna configurations. Note that in (8), we multiplied the lower bound and upper bound by the corresponding user association variable $a_{ik}$, so that if user $k$ is not associated to AP $i$, the corresponding beamwidth is forced to take the value of zero.

B. Effective Throughput

In the mm-wave communications, the total power gain between an AP and a user is composed of three main terms, namely the wireless channel power gain, and the AP and user device’s antenna directivity gains. To make the model analytically tractable, similar to [6] and [9], we approximate the actual beam pattern by a sectorized model, where the power gains are constant inside the main lobe for all angles, and a small value $\epsilon$ for the side lobe gain. Let $\alpha_{ij}^a$ be the observing angle between the users $k$ and $q$ from the point of view of AP $i$. Similarly, let $\beta_{ij}^k$ be the angle between AP $i$ and AP $j$ from the user $k$ standing point (see Fig.1). We denote by $g^a_{ik}$ and $g^u_{ik}$ the AP $i$ and user $k$ antenna gains on the link connecting the nodes to each other, i.e.,

$$g^a_{ik} = \begin{cases} \frac{2\pi}{\phi^a_{ik}}, & \text{if } a_{ik} = 1 \\ \frac{2\pi}{\phi^a_{iq}}, & \text{if } a_{iq} = 1 \text{ and } \alpha_{ij}^a \leq \frac{\phi_{a}^a}{2} \\ \epsilon, & \text{otherwise} \end{cases}$$

and

$$g^u_{ik} = \begin{cases} \frac{2\pi}{\phi^u_{ik}}, & \text{if } a_{ik} = 1 \\ \frac{2\pi}{\phi^u_{iq}}, & \text{if } a_{iq} = 1 \text{ and } \beta_{ij}^k \leq \frac{\phi_{a}^u}{2} \\ \epsilon, & \text{otherwise} \end{cases}$$

Moreover, the effective throughput of the link connecting AP $i$ to user $k$ in bps/Hz (i.e., normalized by the channel bandwidth) is denoted by $r_{ik}$ and can be expressed as

$$r_{ik} = (1 - \frac{T_a}{T}) \log_2(1 + \frac{p_{ik}G_{ik}}{\sigma + \sum_{j \in \mathcal{N}, q \in \mathcal{M}, q \neq k} \sum_{j \in \mathcal{N}, q \in \mathcal{M}, q \neq k} p_{jq}G_{jk}}), \quad (9)$$

where $G_{ik} = g^a_{ik}g^u_{ik}g^v_{ik}$ is the overall power gain and $g^v_{ik}$ is the wireless channel power gain on the link between AP $i$ and user $k$, the term $\sum_{j \in \mathcal{N}} \sum_{q \in \mathcal{M}, q \neq k} p_{jq}G_{jk}$ represents the interference perceived by user $k$, and $\sigma$ is the noise power. Note that the effective throughput depends on the transmit power, operating beamwidths, and the network topology. Additionally, the narrower beamwidths for data transmission and reception enhance the level of signal-to-interference-plus-noise ratio (SINR). Nevertheless, the gain is achieved at the expense of increased alignment overhead and consequently leaves less time for data packet transmission. This captures a trade-off between the effective throughput and the time specified for the beam alignment procedure.

III. FAIR BEAMWIDTH SELECTION AND RESOURCE ALLOCATION

A. Problem Formulation

In this paper, we consider the problem of joint user association, beamwidth selection and power allocation for an indoor mm-wave network. The target of the optimization problem is to maximize the minimum user throughput. Maximizing the minimum throughput yields a fair resource allocation among the users, thus a more uniform QoS can be guaranteed throughout the mm-wave network. Hence, the optimization problem can be formulated as

$$\text{maximize } \min_{k \in \mathcal{M}} \left\{ \sum_{i \in \mathcal{N}} r_{ik} \right\} \quad (10a)$$

subject to:

$$0 \leq p_{ik} \leq a_{ik}P_{\max}, \quad i \in \mathcal{N}, k \in \mathcal{M}, \quad (10b)$$

$$\sum_{k \in \mathcal{M}} p_{ik} \leq P_{\max}, \quad i \in \mathcal{N}, \quad (10c)$$

$$\eta p_{ik} \leq r_{ik}, \quad i \in \mathcal{N}, k \in \mathcal{M}, \quad (10d)$$

$$a_{ik}\psi^a\psi^u \frac{T_p}{T} \leq \phi^a_{ik} \phi^u_k, \quad i \in \mathcal{N}, k \in \mathcal{M}, \quad (10e)$$

$$\phi^a_{\min} \leq \phi^a_k \leq \psi^u, \quad k \in \mathcal{M}, \quad (10f)$$

$$a_{ik}\phi^a_{\min} \leq \phi^a_{ik} \leq a_{ik}\psi^u, \quad i \in \mathcal{N}, k \in \mathcal{M}, \quad (10g)$$

$$\frac{\phi^u_{ik}}{2} \leq \alpha_{ijk} + (2 - a_{ik} - a_{iq})\psi^u, \quad i \in \mathcal{N}, k, q \in \mathcal{M}, \quad (10h)$$

$$\sum_{k \in \mathcal{M}} a_{ik} \leq Z_i, \quad i \in \mathcal{N}, \quad (10i)$$

$$\sum_{i \in \mathcal{N}} a_{ik} \leq 1, \quad a_{ik} \in \{0,1\}, \quad k \in \mathcal{M}, \quad (10j)$$

where the main optimization parameters are transmit powers, beamwidths and the binary user association variables. Constraint (10b) enforces the directed transmit power to an unassociated user to be zero, and the constraint in (10c) is the power budget limit. Furthermore, the constraint expressed in (10d) implies that the ratio between the effective throughput and the power consumption should be greater than the minimum energy efficiency threshold, denoted by $\eta$. In addition, constraint (10e) ensures that the searching time for the beam alignment phase is less than the time slot duration. Moreover, the constraint stated in (10f) limits the range of user device’s beamwidths, and the one in (10g) guarantees that an AP
only directs beams to its associated users. Constraint (10h) ensures that if two user devices are associated to the same AP, their beamwidths should not intersect with each other. Also, constraints (10i) and (10j) imply that the ability of supporting separate transmit beams is restricted by the number of RF chains implemented in the wireless device.

The optimization problem in (10) is a non-convex mixed-integer programming problem whose feasible set is not convex, and thus it is hard to solve in general. In addition to the combinatorial variables and the interference term involved in the rate formula, the channel gains resulted from the beamwidth selection contribute to the non-convexity in the considered mm-wave network problem. Particularly, the channel gains not only are functions of beamwidths, but they also depend on the user association decisions and the network topology. Hence, the complexity of finding the optimal solution is not affordable even for a small size network. Therefore, the problem solution will be accomplished in two phases. In the first phase, we will perform the user association and specify the beamwidths, and in the second phase, we solve the power allocation problem.

B. User Association and Beamwidth Selection

In this section, to circumvent the challenges in problem (10), we propose a low-complexity and suboptimal algorithm for the user association and beamwidth selection phase. It is beneficial that for each AP-user communication link, we first identify the closest (from angle view) mobile device to the user by $Q_{ik} = \arg\min_{q \in \mathcal{M}/k} (\alpha_{ik}^q)$. Then, for all AP-user links, we define the user association and beamwidth selection metric as $\gamma_{ik} = (g_{ik}^Q/g_{Qik}^Q) \log(1 + \alpha_{ik}^Q)$. Note that the angle $\alpha_{ik}^q$ is the smallest angle that AP $i$ observes the neighbor nodes to user $k$. We adopt the logarithmic function for angles because if the closest neighbor node is located outside the sector-level beamwidth, the AP beam to the desired user destination does not intersect with the neighbor device. Thus, after a certain angle threshold, the metric improves less for distant nodes. Additionally, the constant term in the logarithm argument is added to ensure that all metrics have a positive value. The idea of this metric is to prioritize the wireless links with higher gains and users with farther proximate nodes. In this way, in addition to expending less power by APs for supporting high data rates, a larger range for the beamwidths of the users and APs are provided for the selected links. Then, the channel links related to each user are sorted in a decreasing order, according to their metric value. We then find the user whose largest metric is smaller than other user destinations. We then remove the links related to that device will be removed from the set of available links. If all channel links are removed, then set the user beamwidth $\vartheta$ in the set of available channels. After a certain angle threshold, the metric improves less for distant nodes. Additionally, the constant term in the logarithm argument is added to ensure that all metrics have a positive value. The idea of this metric is to prioritize the wireless links with higher gains and users with farther proximate nodes. In this way, in addition to expending less power by APs for supporting high data rates, a larger range for the beamwidths of the users and APs are provided for the selected links. Then, the channel links related to each user are sorted in a decreasing order, according to their metric value. We then find the user whose largest metric is smaller than other user devices. In other words, we try to maximize the minimum user throughput. By differentiating from the estimated data rate for the corresponding communication link, we obtain the optimal value of $\Phi_{ik}^* = \frac{\vartheta^i_{ik}}{\vartheta^u_{ik}}$. Based on the optimal value for the multiplication of the beamwidths, the new lower and upper bounds for the user device beamwidth are introduced. Finally, according to the constraint (10h), if there are feasible solutions for the selected AP and user beamwidths, the corresponding user is associated to that AP and the beamwidths are determined. Particularly, we set the upper bound to the maximum value in the feasible region for the user beamwidth that does not violate the constraint (10h). Note that a wide user beamwidth means that the user observes other APs by its main lobe and the harmful interference from other APs is boosted by the main lobe gain. It also should be noted that since the multiplication of the user device and the AP beamwidths is determined and is fixed to $\vartheta_{ik}$, choosing a very small user beamwidth leads to a wider AP beamwidth, which causes detrimental interference for other users. Therefore, we properly select the user beamwidth to be the average of lower and upper bounds. Moreover, if a user or an AP reaches its limit on the number of supported beams then remove AP $i$ from the set of APs.

Algorithm 1: User Association and Beamwidth Selection

1. Given the set of APs $\mathcal{N}$, users $\mathcal{M}$ and channel gains $\gamma$
2. For all the AP-user links find the closest mobile device (from angle view) to the user
3. Compute the metric value for all available channels $\gamma_{ik} = (g_{ik}^Q/g_{Qik}^Q) \log(1 + \alpha_{ik}^Q)$
4. Set $\mathcal{H} := \gamma$
5. while $\mathcal{H} \neq \emptyset$
6. Find the AP with the largest metric value for each user $\mathcal{I}_k = \arg\max(\gamma_{ik})$
7. Find the user which has the minimum largest metric $\mathcal{K} = \arg\min(\mathcal{I}_k)$
8. Obtain the optimal $\Phi_{ik}^* = \frac{\vartheta^i_{ik}}{\vartheta^u_{ik}}$ by differentiating from the estimated data rate $R_{ik} = \left(1 - \frac{\vartheta^u_{ik}}{\vartheta^i_{ik}}/\gamma_k\right) \log_2 \left(1 + \frac{p_{max}g_{ik}\gamma_k(2\pi)^2}{(\gamma + 1)p_{max}g_{ik}}\right)$
9. Set $LB = \min(\vartheta^u_{ik}, \vartheta^i_{ik})$ and $UB = \min(\vartheta^u_{ik}, \vartheta^i_{ik})$
10. Set $\vartheta$ as the largest value in the range $[LB, UB]$ that does not violate constraint (10h)
11. if $\vartheta \neq \emptyset$ then $\alpha_{ik} = 1$
12. Set the user device beamwidth as $\vartheta^u_{ik} = (\vartheta + LB)/2$, and the AP beamwidth $\vartheta^i_{ik} = \frac{\vartheta^u_{ik}}{\vartheta^u_{ik}}$
13. Remove all the channels related to user $K$ from $\mathcal{H}$
14. if AP $i$ is fully occupied by its limit on the number of supported beams then remove AP $i$ from the set of APs
15. else remove channel $g_{ik}$ from the set of available channels
16. end while

C. Power Allocation

Given the user association and beam angles, the beamforming gains are specified, and consequently, the overall channel gains among the network entities (APs and mobile devices) are determined. Nevertheless, owing to the interference term in the rate formula, problem (10) is still non-convex. To reformulate the problem, we impose a proper threshold on the harmful interference level perceived by the users. Note that by
leveraging the directional transmissions in mm-wave networks, the level of interference is significantly alleviated compared to the omni-directional communication. The mm-wave communication networks illustrate a transitional behavior from the interference-limited to the noise-limited regime [10], where unlike the traditional wireless networks the interference is not a major concern. Hence, similar to the approaches used in [10] and [11], we denote $I_{\text{max}}$ as the maximum allowable interference level, and we define

$$\widetilde{r}_{ik} = (1 - \frac{\tau_{ik}}{T}) \log_2 (1 + \frac{p_{ik} G_{ik}}{\sigma + I_{\text{max}}}),$$

(11)

Then, the epigraph form of the problem can be stated as

\[
\text{maximize}_{\{t, p\}} \quad t
\]

subject to

\[
0 \leq p_{ik} \leq \Pi_{ik}, \quad i \in \mathcal{N}, k \in \mathcal{M}, \quad (12b)
\]

\[
\sum_{k \in \mathcal{M}} p_{ik} \leq P_{\text{max}}, \quad i \in \mathcal{N}, \quad (12c)
\]

\[
\eta p_{ik} \leq \widetilde{r}_{ik}, \quad i \in \mathcal{N}, k \in \mathcal{M}, \quad (12d)
\]

\[
\sum_{i \in \mathcal{N}} \sum_{q \in \mathcal{M}/k} p_{iq} G_{ik} \leq I_{\text{max}}, \quad k \in \mathcal{M}, \quad (12e)
\]

\[
t \leq \sum_{i \in \mathcal{N}} \widetilde{r}_{ik}, \quad k \in \mathcal{M}, \quad (12f)
\]

where $\Pi_{ik} = a_{ik}^* P_{\text{max}}$, and $a_{ik}^*$ is the user association decision. To provide a closed-form solution for the power allocation problem (12), we utilize an effective iterative method such as primal-dual subgradient method [12]. Therefore, the Lagrange function can be formed as

\[
\mathcal{L} = t + \sum_{i \in \mathcal{N}} \lambda_i (P_{\text{max}} - \sum_{k \in \mathcal{M}} p_{ik}) + \sum_{i \in \mathcal{N}} \sum_{k \in \mathcal{M}} \omega_{ik} (\widetilde{r}_{ik} - \eta p_{ik})
\]

\[
+ \sum_{k \in \mathcal{M}} \nu_k (I_{\text{max}} - \sum_{i \in \mathcal{N}} \sum_{q \in \mathcal{M}/k} p_{iq} G_{ik}),
\]

(13)

where $\{\lambda\}$, $\{\omega\}$ and $\{\nu\}$ are the non-negative dual variables corresponding to the constraints (12c), (12d), and (12e), respectively. By applying KKT optimality conditions to (13), we have

\[
\frac{\partial \mathcal{L}}{\partial p_{ik}} = -\lambda_i + \omega_{ik} \frac{\zeta_{ik}}{\ln(2)} \frac{\gamma_{ik}}{1 + \frac{\gamma_{ik}}{\sigma + I_{\text{max}}}} - \eta \omega_{ik}
\]

\[
- \sum_{i \in \mathcal{N}} \sum_{q \in \mathcal{M}/k} \nu_k G_{iq} = 0,
\]

(14)

where $\zeta_{ik} = (1 - \tau_{ik}/T)$ and $\gamma_{ik} = G_{ik}/(\sigma + I_{\text{max}})$. Thereby, the optimal power allocation and the optimal primal variable $t^*$ are given by

\[
p_{ik}^* = \left[\frac{\omega_{ik} \frac{\zeta_{ik}}{\ln(2)} \frac{\gamma_{ik}}{1 + \frac{\gamma_{ik}}{\sigma + I_{\text{max}}}} - 1}{\lambda_i + \eta \omega_{ik} + \sum_{i \in \mathcal{N}} \sum_{q \in \mathcal{M}/k} \nu_k G_{iq}}\right]^{\Pi_{ik}}, \quad (15)
\]

\[
t^* = \min_{k \in \mathcal{M}} \sum_{i \in \mathcal{N}} \widetilde{r}_{ik}(p_{ik}^*), \quad (16)
\]

where $[a]_b = \min\{\max\{0, a\}, b\}$. The dual variables updates using the subgradient method can be obtained as

\[
\lambda_i^{c+1} = \left[\lambda_i^c - \delta_1^c \left(\frac{P_{\text{max}} - \sum_{k \in \mathcal{M}} p_{ik}^*}{\lambda_i^c}ight)\right]^+, \quad (17a)
\]

\[
\omega_{ik}^{c+1} = \left[\omega_{ik}^c - \delta_2^c \left(\frac{\zeta_{ik} \gamma_{ik}}{\ln(2)} \frac{1 + \gamma_{ik}}{1 + \frac{\gamma_{ik}}{\sigma + I_{\text{max}}}} - \eta \omega_{ik}^c\right)\right]^+, \quad (17b)
\]

\[
\nu_k^{c+1} = \left[\nu_k^c - \delta_3^c \left(\frac{I_{\text{max}} - \sum_{i \in \mathcal{N}} \sum_{q \in \mathcal{M}/k} p_{iq}^* G_{ik}}{\nu_k^c}\right)\right]^+, \quad (17c)
\]

where $\delta_c^l$, $l \in \{1, 2, 3\}$, denotes the step sizes at the $c$-th iteration. In the primal-dual optimization approach, the optimal primal variables and optimal power allocation are obtained by (15) and (16). Then, the dual variables will be updated accordingly and the process continues till the iterates converge.

**IV. Simulation Results**

In this section, we present the simulation results to evaluate the performance of the proposed scheme for an indoor mm-wave network with $50 \times 50 \text{m}^2$ area. Wireless channel gains are composed of path loss and shadowing effects, and the path loss model and parameters are adopted from IEEE 802.15.3c standard [1]. Moreover, similar to [1], the maximum transmit power is considered as $P_{\text{max}} = 10 \text{mW}$. The APs are able to support $Z_i = 3$ different transmit beams concurrently. We evaluate the network performance over 1000 different network topologies. We further compare the performance of the proposed scheme to RSSI-based user association with fixed beamwidth for maximizing network throughput (RssMaxTh) policy, which is the adopted approach in the current mm-wave standards, and random user association with fixed beamwidth for Max-Min objective (RndMaxMin).

Fig. 2 depicts the minimum user throughput versus the number of users, where $M/N = 2$.
In this paper, the problem of user association, beamwidth selection and power allocation for an indoor mm-wave networks was studied. The effect of the beam alignment procedure on the user throughput was investigated. The objective was to maximize the minimum user throughput to achieve a fair resource distribution among the mobile users. The resulting optimization problem is combinatorial and non-convex. Considering the transmit beam limits for the network devices, we proposed a low-complexity algorithm for the user association and beamwidth selection. Simulation results indicate the superiority of the proposed scheme to the existing mm-wave based standards in terms of fairness. Thus, our scheme can guarantee a more uniform QoS for the users throughout the network.

**V. Conclusion**

In this paper, the problem of user association, beamwidth selection and power allocation for an indoor mm-wave networks was studied. The effect of the beam alignment procedure on the user throughput was investigated. The objective was to maximize the minimum user throughput to achieve a fair resource distribution among the mobile users. The resulting optimization problem is combinatorial and non-convex. Considering the transmit beam limits for the network devices, we proposed a low-complexity algorithm for the user association and beamwidth selection. Simulation results indicate the superiority of the proposed scheme to the existing mm-wave based standards in terms of fairness. Thus, our scheme can guarantee a more uniform QoS for the users throughout the network.

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