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A Proposal of Access Point Selection Method Based on Cooperative Movement of Both Access Points and Users**

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SUMMARY In recent times, wireless Local Area Networks (wireless LANs) based on the IEEE 802.11 standard have been spreading rapidly, and connecting to the Internet using wireless LANs has become more common. In addition, public wireless LAN service areas, such as train stations, hotels, and airports, are increasing and tethering technology has enabled smartphones to act as access points (APs). Consequently, there can be multiple APs in the same area. In this situation, users must select one of many APs. Various studies have proposed and evaluated many AP selection methods; however, existing methods do not consider AP mobility. In this paper, we propose an AP selection method based on cooperation among APs and user movement. Moreover, we demonstrate that the proposed method dramatically improves throughput compared to an existing method.

key words: *mobile AP, AP selection, throughput, AP cooperative, moving*

1. Introduction

Recently, wireless Local Area Networks (wireless LANs) based on the IEEE 802.11 standard [1] have been spreading rapidly, and connecting to the Internet using this technology has become more common. In addition, the number of public wireless LAN service areas, such as train stations, hotels, and airports, are increasing. A more recent trend is the popularity of portable access points (APs), such as mobile Wi-Fi routers. In addition, the tethering technology has enabled smartphones to act as AP. Consequently, multiple APs can exist in the same area. In this situation, wireless terminal users must select one of many APs.

The standard wireless LAN protocol based on IEEE 802.11 usually selects the AP with the highest Received Signal Strength Indicator (RSSI) [2]. However, even if there are multiple APs, this AP selection method causes uneven AP loading when wireless terminals are disproportionately distributed to a single AP. This causes traffic congestion and AP overload, which greatly reduces communication quality. [3] shows that an AP selection method that considers the highest RSSI value may not provide fair bandwidth allocation or effective bandwidth utilization in environments such as train stations and hotel lobbies. Furthermore, multi-rate wireless LAN environments where terminals use multiple transmission rates suffer from a performance anomaly [4], [5]. This performance anomaly causes throughput degradation because the AP is connected to a terminal with an extremely low transmission rate. As a result, the communication quality decreases drastically.

To solve this problem, various AP selection methods [6]–[13] have been proposed and evaluated. In particular, [13] proposed an AP selection method based on cooperative movement of a new joining user and demonstrated that it improves system throughput (User-Only-Mobility Method: UOMM). Note that the system throughput means the sum of the throughput of all APs in the system. Our proposed AP selection method is based on the aforementioned study [13]. Other studies [14]–[18] have shown the effectiveness of cooperative mobility of users. For example, [14] proposed a traffic control method based on user collaboration, and [15] introduced a mechanism to increase the spectral efficiency of cellular OFDMA systems through the cooperation of users accessing wireless cellular networks. In addition, [16]–[18] revealed the relationship between route selection of the device user and communication quality.

Previous studies have not considered AP mobility; however, AP mobility will become more common in the future. Here, it is expected that the throughput can be improved dramatically by considering the cooperative movements of both APs and users. Note that we primarily assume a mobile AP (3G/LTE equipped portable Wi-Fi AP) that can move easily rather than a fixed AP. The example of AP movement is that the device owner moves a mobile Wi-Fi router to a more convenient location in a conference room. In this paper, we propose an AP selection method based on cooperative movements of both APs and users (User-AP-Cooperative-Mobility Method: UACMM) [19]. Furthermore, we evaluate the characteristics of UACMM [20]. Additionally, we evaluate system throughput under the assumptions that the movable distance of both users and APs are discrete values or continuous values. The main purpose of our paper is to clarify the effects of cooperative movement of both the user and the AP. Essentially, this paper at-

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Table 1 Relationship between distance and transmission rate (IEEE 802.11g) [13].

Distance d m	5	7	9	20	25	40	50	60
Transmission rate b Mbps	54	48	36	24	18	12	9	6
Effective transmission rate b_{eff} Mbps	26.1	24.4	20.4	15.3	11.9	8.5	5.8	4.7

tempts to clarify the relationship between the cost (sum of the distance between an AP and users) and the improvement of system throughput by numerical simulations.

The remainder of this paper is organized as follows. Section 2 describes the performance anomaly and the overview of UOMM. Next, in Sect. 3, we introduce the UACMM. We then evaluate the UACMM in Sect. 4. Finally, Sect. 5 provides conclusions and suggestions for future work.

2. Related Work

In this section, we explain the performance anomaly faced by multi-rate wireless LANs. We also provide an overview of the AP selection method based on user cooperative movement. In this paper, we call this method User-Only-Moblity Method (UOMM).

2.1 Performance Anomaly in Multi-Rate Environment

Performance anomaly degrades the throughput of all terminals connected to one AP in a multi-rate environment. The total throughput of all terminals connected to the same AP becomes nearly equal to that of the terminal with the lowest transmission rate. This problem is caused by Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). In a wireless LAN environment, each terminal can obtain a fair transmission opportunity. Specifically, CSMA/CA provides each terminal with the same number of accesses to the communication channel. However, in a multi-rate environment, the time the terminal occupies the channel depends on its transmission rate. Since a terminal with a high transmission rate has a short channel occupancy time, the wait time of other terminals decreases. Conversely, since the channel occupancy time of a low transmission rate terminal is long, the wait time of other terminals increases. In this situation, the transmission cycle of terminals with high transmission rates becomes the same as that of the terminal with the lowest transmission rate. Accordingly, the throughput of the high transmission rate terminals decreases.

In a multi-rate environment, it is known that the throughput θ_a of the a-th AP can be estimated by Eq. (1) [21]. Equation (1) shows that AP throughput is equal to the harmonic average value of the transmission rate of terminals connected to the same AP in a multi-rate environment.

$$\theta_a = \frac{n_a}{\sum_{i=1}^{n_a} (b_{i,a})^{-1}} \tag{1}$$

In Eq. (1), n_a and $b_{i,a}$ denote the number of terminals connected to the a-th AP and the transmission rate of the i-th

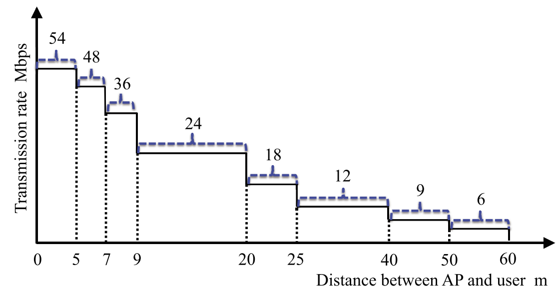

Fig. 1 Stepped transmission rate.

terminal connected to the a-th AP, respectively. We assume that Eq. (1) indicates AP throughput. The throughput $\theta_{u,a}$ of the u-th terminal connected to the a-th AP is obtained by dividing by n_a (Eq. (2)) because all terminals connected to the same AP have the same $\theta_{u,a}$ values.

$$\theta_{u,a} = \frac{\theta_a}{n_a} \tag{2}$$

2.2 AP Selection Method Based on User Cooperative Movement: UOMM

Here, we briefly explain the UOMM [13]. We use this method as a baseline in comparative evaluations. The UOMM maximizes system throughput Θ by cooperative actions of a new joining terminal (new user). Note that Θ indicates the sum of the throughput of all APs in the system. The action is to move the new user to the AP within an acceptable area (distance) before establishing connection.

The new user has movable distance d_{th}, and the new user attempts to connect to the AP that can maximize Θ. To improve user and system throughput, the new user is assumed to be willing to move up to d_{th}. Here, [13] investigated the relationship between the transmission rate of the terminal and the distance between the AP and the terminal (Table 1). Note that b_{eff} in Table 1 is an effective transmission rate which is the transmission rate in a real environment considering the existence of events like flame collision. Furthermore, [13] used the stepped transmission rates (Fig. 1) based on the Table 1 for their evaluations. In this paper, we use the same stepped transmission rate as [13] for evaluations (Sect. 4).

Here, the AP selection is performed as follows: First, throughput for all APs in the system is calculated assuming that the new user moves to an AP within d_{th}. If several APs offer the same maximum throughput value, the AP with the shortest move distance is selected. According to the above consideration, the AP selection method based on user movement is defined as an optimization problem; identifying AP a^* that offers the maximum Θ and minimum move distance

$\mathbf{m}^*$ with a new user connection. Note that the maximum movable distance of the user is d_{th}. In this paper, the mean of *move distance* is the distance which users have actually moved. Furthermore, the mean of *movable distance* is the distance which users may move. That is, the user move distance is less than d_{th}.

3. AP Selection Method Based on AP Movement: UACMM

This section describes the proposed AP selection method based on cooperation of both the AP and the user movement, and we call this method User-AP-Cooperative-Mobility Method (UACMM) in this paper. For simplicity, we explain the procedure for selecting a single AP.

3.1 Overview of UACMM

The UACMM is illustrated in Fig. 2. This method is an extension of [13], in which movable distance is set for both users and APs. We define the movable distance of a new user and that of the i-th AP as d_{th} and $e_{i,th}$, respectively. n_a denotes the number of users connected to the a-th AP. The new user and AP can move freely within the specified distance in the system area. The new user selects the AP to maximize system throughput Θ. Here, Θ has the same meaning as above. The new user moves to the position where system throughput can be maximized. The AP moves to maximize Θ while minimizing the reduction in the transmission rates of users already connected to the AP. If there are several APs that can maximize Θ, this method selects the combination that has the shortest move distance for the AP and user. The UOMM is the same as the UACMM if $e_{i,th} = 0$.

To define the UACMM as an optimization problem, an objective function and constraints are defined as follows. The objective function maximizes Θ by connecting the new user to the AP. Θ depends on the selected AP a^*, the move distance of new user to the AP $\mathbf{m}^*$, and move distance of the AP $\mathbf{l}^*_{a^*}$. The constraint conditions are the movable distances of the user and the AP. The maximum movable distance of a new user and maximum movable distance of the i-th AP are denoted d_{th} and $e_{i,th}$, respectively. In real environments, the number of users is usually limited by provider policies and AP specifications; thus, in this paper, the maximum number of users that can connect to any one AP is N.

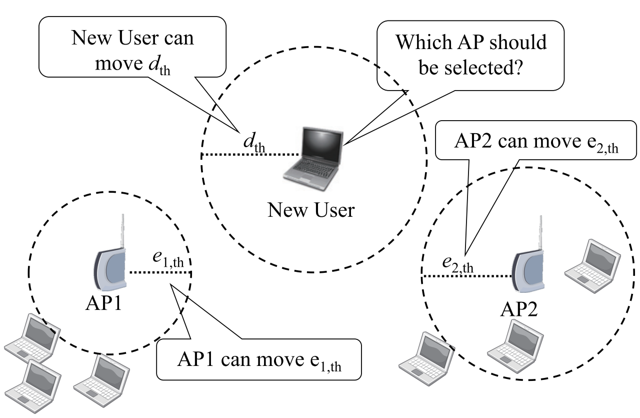

Fig. 2 AP selection method based on AP cooperative movement of both the AP and the user.

3.2 Determination of Communication Position of APs and Users to Maximize System Throughput

This subsection describes a method that yields the communication positions of APs and users to maximize system throughput. Figure 3 illustrates initial positions of the AP and users. In Fig. 3, three users are currently connected to the AP and one new user intends to connect to this AP. We assume that each AP and user can determine position information (coordinates) of each terminal using appropriate tools, such as GPS technology. In the UACMM, we assumed that the AP maintains the coordinates of all terminals connected to the AP and instructs the destination for a new joining user. Note that the new joining user notifies all APs of its position when the user joins. This control can be operated in an environment where IEEE802.11k [22] is implemented generally. Note that this system assumes movement on a two-dimensional surface. In other words, users and APs exist on the same plane.

First, the new user moves toward the gravity point (G_1) of the plane formed by all existing users connected to the AP within the new user's movable distance (d_{th}) (Fig. 4 ①). If

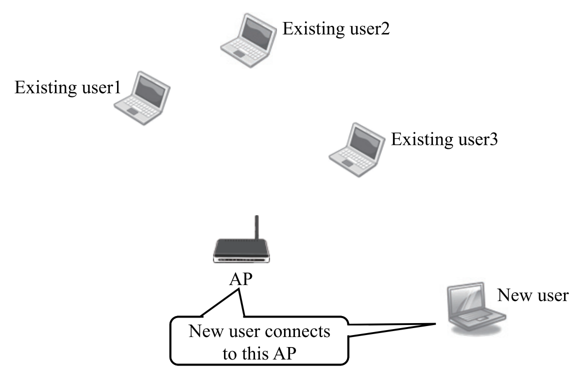

Fig. 3 Initial position of APs and users.

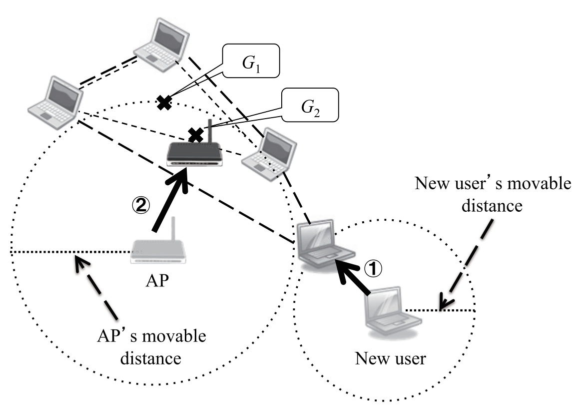

Fig. 4 Determination of communication position of APs and new users.

Algorithm 1 An algorithm of UACMM.

```
new user u arrives
user u notifies all AP of both d_th and the position of u
a ⇐ 1
a* ⇐ 1
|m*| ⇐ d_th
|l_a*| ⇐ e_1,th
Θ_a* ⇐ 0
while All AP do
    AP a calculates G_1, which is the gravity point of the plane formed by all existing users connected to the AP a
    AP a calculates the position of new user and move distance of new user |m|
    AP a calculates G_2, which is the gravity point of the plane formed by both all existing users connected to the AP a and new user u
    AP a calculates the next position and move distance |l_a|
    AP a calculates system throughput Θ
    if Θ_a* == Θ then
        if |m*| + |l_a*| > |m| + |l_a| then
            a* ⇐ a
            |m*| ⇐ |m|
            |l_a*| ⇐ |l_a|
            Θ_a* ⇐ Θ
            G*_1 ⇐ G_1
            G*_2 ⇐ G_2
        end if
    end if
    if Θ_a* < Θ then
        a* ⇐ a
        |m*| ⇐ |m|
        |l_a*| ⇐ |l_a|
        Θ_a* ⇐ Θ
        G*_1 ⇐ G_1
        G*_2 ⇐ G_2
    end if
    a ⇐ a + 1
end while
user u moves toward the G_1
AP a* moves toward the G_2
user u connects to AP a*
```

the new user can reach G_1, it stops at G_1. If the new user cannot reach G_1, it stops at the point that minimizes the distance between G_1 and themselves. Here, the gravity point of the plane is defined as the point that minimizes the sum of the squares of the distances from each vertex constituting the plane. By this procedure, throughput will improve for the new and existing users after the AP moves. If there are no existing users, the new user moves to the position of the AP. If only one user is connected to the AP, the new user moves to the position of the existing user. If only two users are connected to the AP, the new user moves to the midpoint of the line connecting both existing users. Next, the AP moves to the gravity point (G_2) of the plane formed by both the new user and all existing connected users. The AP moves up to its movable distance ($e_{AP,th}$) (Fig. 4 ②). If the AP can reach G_2, it stops at G_2. If the AP cannot reach G_2, it stops at the point that minimizes the distance between G_2 and the AP. In addition, if there is no existing user, the AP moves to the position of the new user. If only one user is connected to the AP, the AP moves to the midpoint of the line connecting the new and existing user. Through movement of the AP and the new user, all existing users and the new user can minimize the distance to the AP without exceeding the movable distance upper limit. Thus, users can communicate at a higher transmission rate because the distance between users and the AP is decreased. As a result, these procedures can maximize system throughput. Our strategy use [23] as a reference. Note that UACMM performs the above procedures for all APs and only the AP with the maximum Θ value among all APs moves. Algorithm 1 shows the series of actions for the proposed method. In addition, the UACMM can be performed using $O(N_{STA} \cdot N_{AP})$, where N_{STA} is the number of terminals and N_{AP} denotes the number of APs.

Note that our study includes the AP selection problem and the AP placement problem. In addition, improvement of throughput by cooperative movement of both APs and users is demonstrated. These results are useful for AP selection and AP placement. Furthermore, each terminal uses saturated traffic, and we consider the performance anomaly in our evaluation (see Sect. 4). The effect of the performance anomaly depends on the distance between AP and users; therefore, if both AP and users move cooperatively, throughput can be improved effectively. A method for distributing required load information for autonomic load balancing has been investigated [24], [25]. We intend to include investigation of the distribution of required load information to achieve autonomic load balancing in future work.

4. Throughput Evaluations

This section evaluates the UACMM using a simulator written in C language. We focus on system throughput and average AP throughput. We evaluate the following four characteristics.

- I Impact of movable distance of APs on system throughput performance
- II Impact of the number of APs on AP throughput performance
- III Throughput evaluation when joining and leaving users exist
- IV Throughput evaluation considering disconnection methods of a user

Characteristic I shows the effectiveness of AP movement, a key idea of the UACMM. Characteristic II indicates the effectiveness of AP movement in terms of the throughput of each AP. Characteristic Ⅲ assumes a typical wireless communication environment. Characteristic Ⅳ indicates a case when a user who affects communication quality negatively is disconnected to guarantee communication quality. In addition, we evaluate system throughput under the assumptions that the move distances of both users and APs are discrete or continuous values. Note that AP throughput is calculated by Eq. (1). Here, the radio property of the physical layer changes drastically if the communication environment changes. In this situation, the Media Access Control (MAC) characteristics also change because MAC depends on the physical layer. If we assume the physical layer and MAC, it is expected that the potential effect of cooperative movement becomes unclear. Therefore, we do not consider the physical layer and MAC in the evaluations. In future, we will evaluate the proposed method using a network simulator to consider real environment characteristics, such as control overhead and interference between APs.

4.1 Movable Distance of APs and Throughput Performance

First, we evaluate the relationship between system throughput and AP movable distance. Figure 5 shows the system configuration used in the evaluation. In a 120 m × 120 m area, there are APs at coordinates (30 m, 60 m) and (90 m, 60 m). This system configuration follows a previous study [13]. In the initial state, only APs are present. Next, both a x-coordination and a y-coordination of a user is set by continuous uniform random numbers which range is $[0, 120]$. Here, 120 indicates the side length of the system area (see Fig. 5). Then, the users appear at the position that is decided by the random value in a moment. Also, the users can move to the specified position calculated by the Algorithm 1 in a moment. That is, we assume that each user turns on the terminal at two points in the system area, where the initial position of user and destination point calculated by the Algorithm 1. In the evaluations of UACMM and UOMM, the appearance position of users for i-th ($1 \leq i \leq 30$) trial is same. All users connect to the AP that offers the highest system throughput. In this situation, we show that the UACMM improves system throughput compared to two existing methods, a minimum distance selection method and UOMM. In the minimum distance selection method, the user connects to the nearest AP without moving. This method is similar to the AP selection method using RSSI values as the metric, which is a common approach. Table 1 shows the user transmission rate employed in previous studies, and we use the stepped effective transmission rate b_{eff} as the transmission rate. This study assumes saturated UDP flow (the user always has data to send). Each simulation ran for 30 trials, and the results are the averages of the 30 trials. The position of the user changed in each simulation.

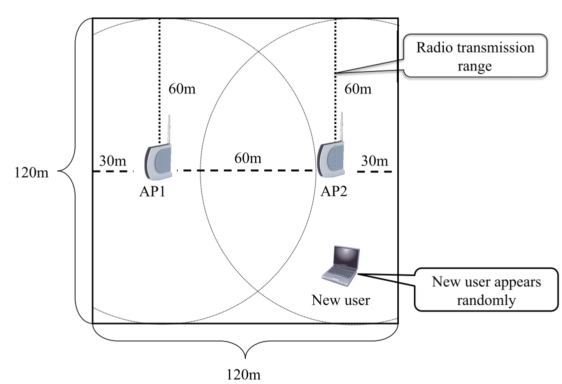

Fig. 5 Initial configuration of system (1).

Figure 6 and Fig. 7 show the throughput improvement ratio of the UACMM compared to the minimum distance selection method and UOMM, respectively. In this paper, we define the throughput improvement ratio as follows:

$$\text{Improvement ratio} = \frac{\theta_{UACMM}}{\theta_{existing}}. \quad (3)$$

In Eq. (3), $\theta_{existing}$ is the system throughput of minimum distance selection method or UOMM, and θ_{UACMM} is the system throughput of UACMM. In Fig. 6 and Fig. 7, the number of joining users is 1, 5, and 10. In Fig. 6 and Fig. 7, the horizontal and vertical axes represent the movable distance of the AP and the movable distance of a new user, respectively. The movable distance of both the AP and the user changes every 10 m. Here, the aim of this paper is to clarify the effectiveness of cooperative movement of both the APs and the users, which greatly contributes to the system throughput improvement. Therefore, we consider more detail evaluation as a future work. In Figs. 6 and 7, the

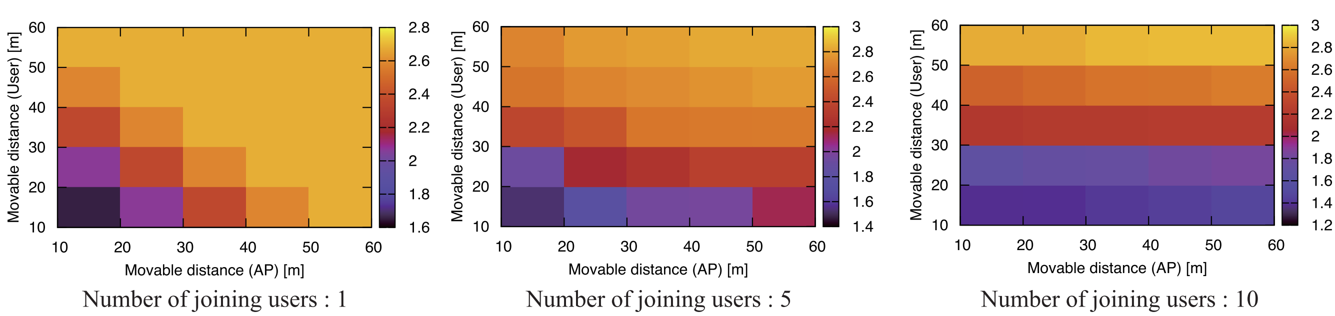

Fig. 6 Relationship between system throughput and movable distance of both the AP and new user (vs. minimum distance selection method).

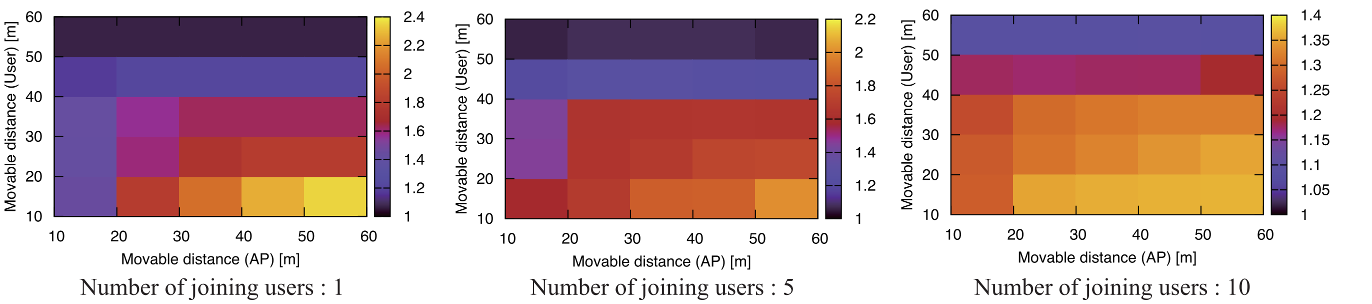

Fig. 7 Relationship between system throughput and movable distance for both the AP and new user (vs. UOMM).

color of the square area ($\alpha \leq e_{i,th} < \alpha + 10, \beta \leq d_{th} < \beta + 10$)($\alpha = \{10, 20, 30, 40, 50\}$, $\beta = \{10, 20, 30, 40, 50\}$) means the system throughput improvement ratio where $e_{i,th}$ and d_{th} mean the movable distance of i-th AP and the user, respectively. Note that the system throughput improvement ratio of one square includes the boundary of bottom and left side. From Fig. 6, if the number of joining users is 1, the system throughput for the UACMM is 2.8 times greater than that of the minimum distance selection method when the UACMM can obtain the highest values. In addition, with 5 and 10 users, the UACMM can triple system throughput compared to the minimum distance selection method. However, compared to the minimum distance selection method, when the number of joining users is high and user movement distance becomes short, the UACMM does not improve throughput significantly even if AP movable distance increases because it is difficult to improve throughput by an AP movement due to the large number of users. Therefore, throughput improvement is best achieved by increasing the movable distance of users rather than that of the AP.

Figure 7 shows the improvement ratio of system throughput compared to UOMM. For the UACMM, the movable distance of both APs and new users is 10 m to 60 m. When the number of joining users is 1, the UACMM improves system throughput by up to 2.4 times that of UOMM. If there are 5 and 10 users, system throughput is improved by up to 2.2 times and 1.4 times, respectively. Here, throughput does not improve significantly when user movable distance is greater than 60 m because users can reach a position where they can obtain a higher transmission rate when the user movable distance increases. Therefore, the system can obtain higher throughput without AP movement. In summary, the UACMM can improve throughput significantly compared to existing methods.

Here, we evaluate the system throughput when the sum of the AP and user movable distance is fixed. The experimental environment is the same as in the previous evaluations. Figure 8 shows the result when the total movable distance is 60 m. In Fig. 8, the horizontal axis shows the number of joining users in the system, and the vertical axis shows system throughput. Note that the result of UOMM is for the same case when the AP movable distance is 0 m. From Fig. 8, if the number of joining users is high, the cooperative movement of both APs and users is effective for the system throughput compared to the case when a AP or a user only moves. Furthermore, the UACMM improves system throughput by approximately 25 Mbps compared to results in the UOMM when the number of joining users is 10 and UACMM is (AP: 10 m, User: 50 m). In addition, Fig. 8 shows that if the number of joining users is high, the system throughput can drastically improve when the movable distance of the user is greater than the one of the AP. This is because that it is difficult to improve the throughput by only using AP movement or user one when a large number of users are widely distributed in the system area. From this result, if the AP and user movable distances are equal, cooperative movement (AP and user) is more effective than only user movement.

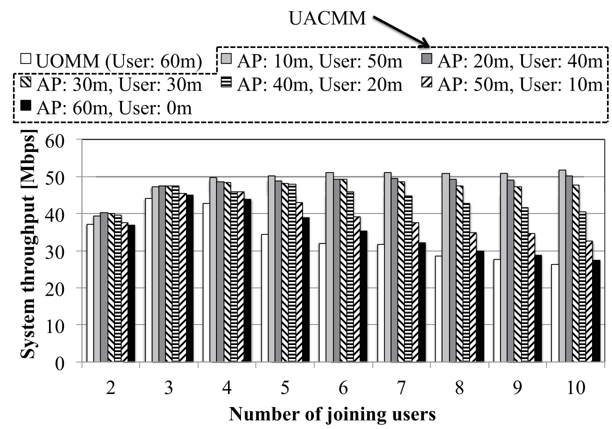

Fig. 8 Relationship between system throughput and movable distance (total movable distance is 60 m).

4.2 Throughput Performance vs. Number of APs

In this subsection, we evaluate the average AP throughput when the number of APs in the system changes. We use an area of 120 m × 120 m as in Sect. 4.1. In the initial state, a specified number of APs are set in the area (Fig. 9). Subsequently, users enter the area randomly until the number of users connected to the AP becomes greater than two. At that point, we calculate the average AP throughput. All APs have connected users since the number of user is greater than two. Furthermore, the performance anomaly may occur when at

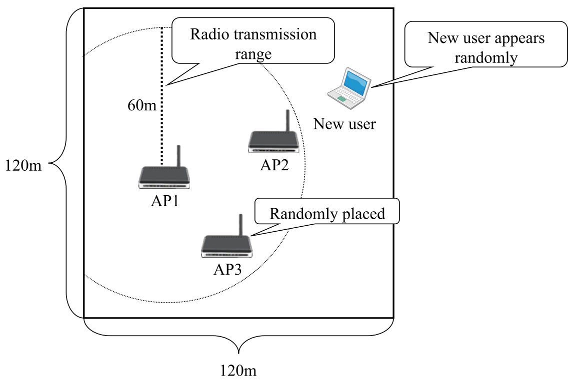

Fig. 9 Initial configuration of system (2).

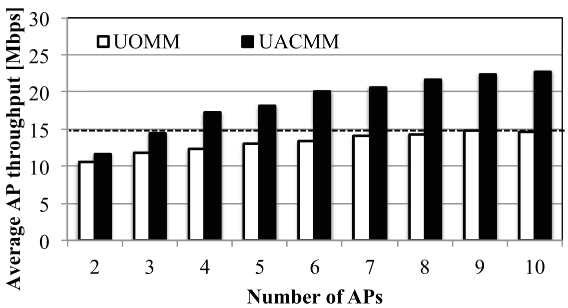

Fig. 10 Throughput performance vs. the number of APs in the system (movable distance; AP 10 m, new user 10 m).

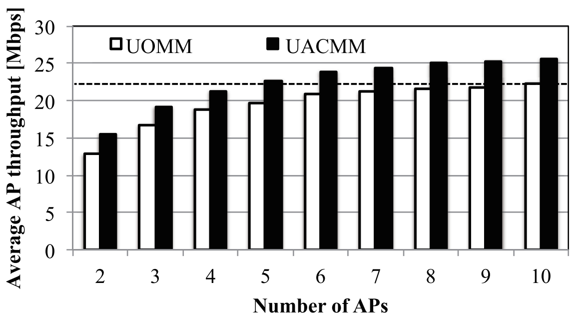

Fig. 11 Throughput performance vs. number of APs in the system (movable distance; AP 30 m, new user 30 m).

least two or more users connect one AP. The transmission rate, traffic type, and the number of trials of the simulation are the same as those in Sect. 4.1.

Figure 10 shows average AP throughput with the UOMM and the UACMM. The user movable distance is 10 m in both methods, and AP movable distance is 10 m in the UACMM. From Fig. 10, the maximum difference between the UACMM and the UOMM is approximately 8 Mbps when there are 10 APs. Moreover, with 3 APs, the UACMM attains the same average AP throughput as the UOMM with 10 APs (dotted line in Fig. 10).

Next, we discuss the results shown in Fig. 11 when the user movable distance is 30 m in the UOMM and the movable distance of both users and APs is 30 m in the UACMM. Since the user and AP can move the same distance (30 m), the total movable distance is 60 m. This result shows that the maximum difference between the UACMM and the UOMM is approximately 4 Mbps when there are 9 APs. Moreover, with 5 APs, the UACMM can attain the same average throughput achieved by the UOMM with 10 APs (dotted line in Fig. 11).

From the above results, it is clear that the UACMM can achieve higher average AP throughput with fewer APs than the UOMM.

4.3 Evaluation of Throughput When Joining and Leaving Users Exist

Join and leave users can be modeled using a queuing model. Here, the M/M/1 queue model is used to model joining and leaving users. In this subsection, the relationships between the utilization rate ρ for M/M/1 join and leave user model and system throughput are evaluated. Note that the relationship among ρ, λ, and μ is defined as follows:

$$\rho = \frac{\lambda}{\mu}. \tag{4}$$

In Eq. (4), λ and μ indicate user arrival rate and service rate, respectively. The system configuration is the same as that in Sect. 4.1 (Fig. 5). In the initial state, there are only APs in the system. Next, the specified number of users appears randomly. Then, all users connect to the AP with the highest system throughput. In this evaluation, we calculate the average throughput until all users leave when ρ changes. Then, we compare the UACMM to the UOMM using throughput improvement ratio based on a minimum distance selection method. The transmission rate, number of trials of the simulation, and traffic type are the same as in Sect. 4.1. In this evaluation, the number of joining users is 100, and they have joining time and service time defined by an exponential distribution. The exponential distribution is yielded by a specified utilization rate ρ, user arrival rate λ, and service rate μ. The service rate μ is 0.1 and the arrival rate λ is set to $\{0.05, 0.06, 0.07, 0.08, 0.09, 0.1\}$. Note that the aim of this paper is to show the effectiveness of the cooperative movement of both users and APs for the system throughput. Thus, we will evaluate the more detail characteristics about the relationship among the arrival rate, the service rate, and the system throughput in the future works. The number of users that can connect to AP N is 10. If the number of connected user is 10, a new user waits for to connect to an AP until a connected user leaves. Here, this evaluation assumed that a user joins and connects to the AP, and then the user communicates during the service time. When communication is finished, the user shutdowns its terminal and the user leaves the system. When the user communicates with an AP, the user's terminal sends the saturated UDP flow.

If there is an upper limit of the connectable user number, the queue length becomes greater as ρ increases. Consequently, the number of users reaches the limit immediately,

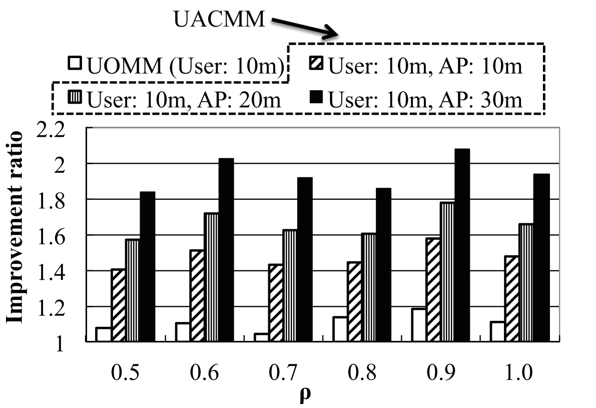

Fig. 12 Utilization rate (ρ) vs. improvement ratio of system throughput (new user movable distance: 10 m).

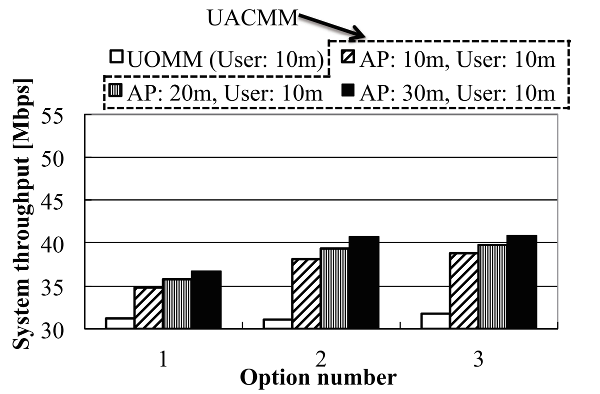

Fig. 14 Relationship between system throughput and each option (AP capacity: 2, new user movable distance: 10 m).

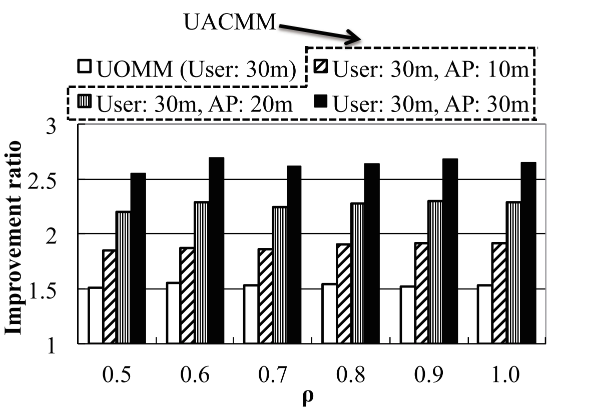

Fig. 13 Utilization rate (ρ) vs. improvement ratio of system throughput (new user movable distance: 30 m).

and the throughput becomes nearly stable, even if the queue length has increased to maximum capacity. Since the distance between an AP and users in the UACMM is less than the UOMM, a user can send data at a higher rate. In addition, the throughput of the UACMM improves.

Figure 12 shows the relationship between the throughput improvement ratio and ρ when the movable distance of a user is 10 m. The x-axis and y-axis show ρ and the throughput improvement ratio compared to the minimum distance selection method, respectively. From Fig. 12, the average improvement ratio of the UOMM is 1.1 times. Conversely, even if ρ changes, the UACMM can improve 1.5 and 1.9 times when the AP movable distance is 10 m and 30 m, respectively.

Figure 13 shows similar results when the user movable distance is 30 m. From Fig. 13, the average improvement ratio of the UOMM is 1.6 times. On the other hand, even if ρ changes, the UACMM can improve 1.9 and 2.6 times when the AP movable distance is 10 m and 30 m, respectively. Therefore, we found that the UACMM can improve throughput dramatically compared with the UOMM even if the frequency of user's join and leave is high.

4.4 Evaluation of Throughput Considering the Disconnection Method of a User

Here, we evaluate throughput when the number of connected users reaches the upper limit and one user is forced to disconnect due to a new joining user. In this situation, it is assumed that, given a network policy, the AP disconnects the user with the most negative impact on AP throughput in order to maintain communication quality. We consider three methods for disconnection and assume that the AP has no resources available for a new user. In the first method, one user is selected randomly (option 1). In the second method, the user furthest from the AP is selected (option 2). In the third method, all users return to their initial position and then move to the optimal position to connect to the AP. Then, the connected user furthest from AP is selected (option 3). The system configuration used in Sect. 4.1 is also used in this evaluation. Moreover, the AP has the acceptable number of users N. In this evaluation, there are two APs in the initial system. Then, the acceptable users join the system and they select the AP. Furthermore, if one user joins the system, AP disconnects one user according to the option. This evaluation investigates the relationships between the acceptable number of users N and system throughput.

Here, it is expected that the effective selection the user to be disconnected will affect system throughput. The user furthest from the AP that has the lowest transmission rate decreases system throughput. Thus, rather than selecting randomly, if the user furthest from the AP is selected for disconnection, system throughput can be reduced. In addition, the UACMM can maintain higher throughput compared to the UOMM because the distance between the AP and user in the UACMM is shorter.

Figure 14 and Fig. 15 plot the relationships between each option and system throughput when the acceptable number of users is 2. The x-axis and y-axis show the option number and system throughput, respectively. Figure 14 and Fig. 15 illustrate the case in which the user movable distance is 10 m and 30 m, respectively. The AP movable distance in each figure is set to 10 m, 20 m, and 30 m. From

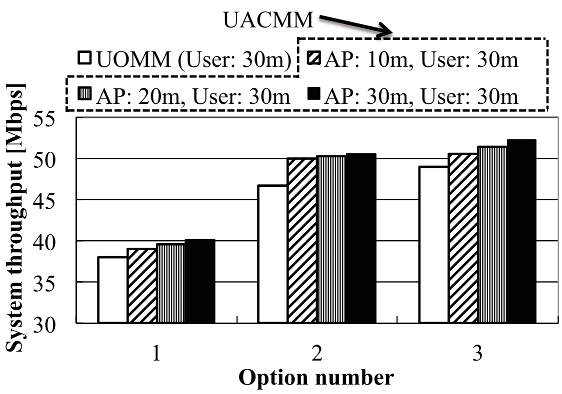

Fig. 15 Relationship between system throughput and each options (AP capacity: 2, new user movable distance: 30 m).

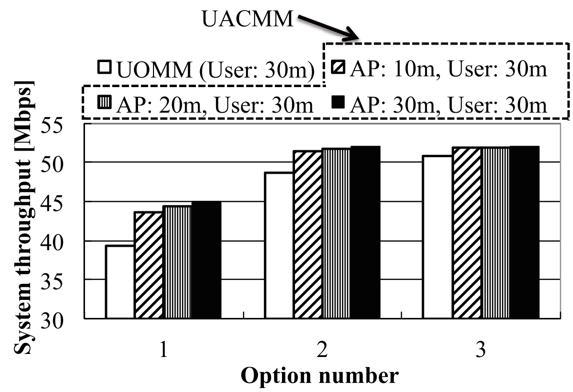

Fig. 17 Relationship between system throughput and each option (AP capacity: 10, new user movable distance: 30 m).

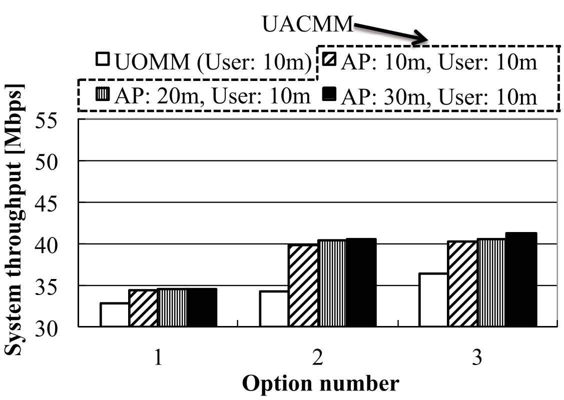

Fig. 16 Relationship between system throughput and each option (AP capacity: 10, new user movable distance: 10 m).

Fig. 14, the system throughput of the UOMM for all options is approximately 30 Mbps. In contrast, for option 1, the UACMM can achieve 35 Mbps and 38 Mbps when the AP movable distance is 10 m and 30 m, respectively. Furthermore, if option 2 or 3 are used to disconnect the user that is affecting system throughput, throughput improves from 39 Mbps to 40 Mbps by increasing the AP movable distance in UACMM. Figure 15 indicates that the UACMM achieves nearly equal performance as the UOMM when the user movable distance is 30 m. This is because the UOMM can reduce the distance between a user and an AP when the movable distance is 30 m. Consequently, even if the AP disconnects any user, the difference between the UACMM and the UOMM method becomes small. However, in the case of options 2 and, 3 the UACMM can achieve higher throughput (approximately 5 Mbps) than the UOMM. Therefore, the UACMM can improve throughput with any of the three disconnection methods.

Figure 16 and Fig. 17 show results when the acceptable number of users increases (10 users). The results shown in Fig. 16 and Fig. 17 are similar to the results presented in Fig. 14 and Fig. 15, respectively. It is evident from Fig. 16 and Fig. 17 that the difference of throughput between the UACMM and the UOMM is small compared with $N = 2$ because there are a significant number of users. However, the throughput of the UACMM is greater than that of the UOMM for all options. In summary, we confirmed that the UACMM can improve throughput compared to the UOMM regardless of the disconnection method used and when the acceptable number of users changes.

4.5 Realistic Solution

Here, we evaluate the UACMM's performance in a more realistic situation. In particular, we evaluate system throughput under the assumption that the move distances of both users and APs are discrete or continuous values.

4.5.1 Discrete Destination Points

In the previous evaluations, the destination points of the user and the AP were taken to be continuous values. However, it is expected that discrete destination points will be common in actual environments. This section evaluates the system throughput under the assumption that the move distances of both users and APs are discrete or continuous values. If the difference of these system throughput becomes larger, we do not show the effectiveness of the proposal sufficiently. In order to clarify the difference, we evaluated the performance over the simple model without AP selection.

Figure 18 shows the system configuration considered in this experiment. The two tuple shown in the bottom of the AP or each user show the coordinates (x-axis, y-axis) of the AP or each user in Fig. 18. This system has one AP in a 120 m × 120 m area, and 3 existing users are connected to it. The movable distance of both the AP and a new user is 20 m. This emphasizes the difference between discrete and continuous destination points. If the destination points are discrete values, the region is divided by a mesh with an interval of 1 m, and both the AP and new users can be set only on the grid points. Thus, the AP and a new user move to the grid point that is the closest to the gravity point. Note that, the aim of this paper is to propose and to evaluate an AP selection method considering the cooperative moving of users and APs. Therefore, the evaluation considering methods to

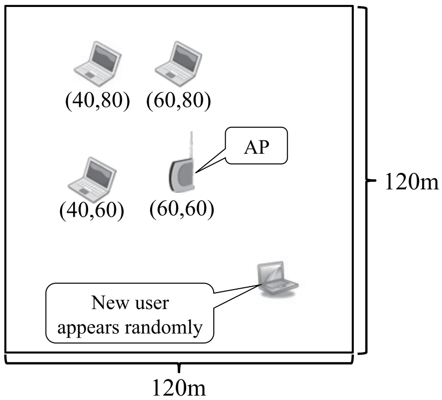

Fig. 18 Initial configuration of system (3).

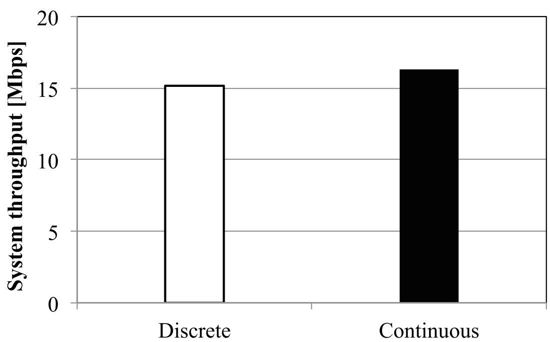

Fig. 19 System throughput with discrete and continuous destination points.

determine the realistic grid is our future work. The number of existing users is 3, and new users appear at randomly in the area same as subsection 4.1. The transmission rate, type of traffic, and number of trials in the simulation are the same as those of the simulation described in Sect. 4.1.

Figure 19 shows a comparison of the throughput. From Fig. 19, continuous and discrete destination points yield nearly equal throughput; the difference is approximately 1.1 Mbps, and the relative error is approximately 5 %, which is very small. Therefore, since discrete destination points (realistic solution) yield nearly the same results as continuous destination points, it is confirmed that the UACMM yields realistic values.

4.5.2 Comparing Gravity Point and *p*-Median

Next, we discuss coordination of both APs and users to maximize system throughput. Note that we assume discrete destination points. In this situation, coordination is possible by techniques that are not based on the gravity point, such as the *p*-median technique [26]. Finding the *p*-median has been widely studied [27]. The *p*-median problem calls for finding the *p* facilities that minimize the total distance between the demands and the selected facilities. This study uses the *p*-median as the point at which total throughput is maximized. The *p*-median problem is known to be NP-hard [28]. In this experiment, we investigate how system

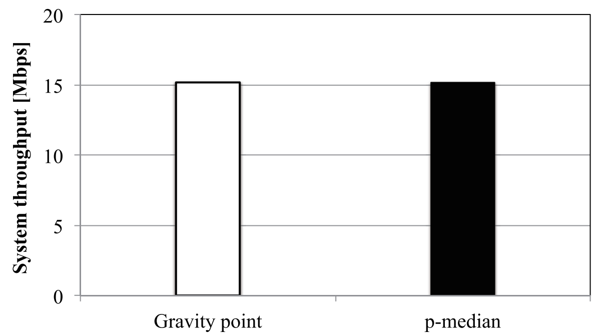

Fig. 20 Comparing system throughput achieved with gravity point and *p*-median.

throughput changes when coordination is realized by the gravity point or the *p*-median. The experimental environment is the same as that in Sect. 4.5.1.

Figure 20 shows a comparison of throughputs. From Fig. 20, it is evident that the *p*-median approach yields nearly equal throughput as the gravity point approach because the transmission rate is given by a step function. However, even if the transmission rate is continuous, it is expected that the difference would remain minor because, in this experiment, the grid points (the destination points) are close to each other. In other words, *p*-median position is nearly equal to the gravity point position. However, the gravity point can be found more quickly than the *p*-median. Thus, using the gravity point for AP selection is very effective in terms of time complexity.

5. Conclusion

This paper has proposed and evaluated an AP selection method that considers the movement of users and APs (UACMM). We evaluated the effectiveness of portable APs, such as mobile Wi-Fi routers, to increase system throughput in a multi-rate wireless LAN environment. The UACMM can improve system throughput and AP average throughput dramatically compared to the UOMM that only moves a new user because the AP can move to a position where existing users can obtain higher transmission rates. Furthermore, we have evaluated system throughput under the assumption that the move distances of both users and APs are discrete or continuous values.

Future work will include the following evaluations:

- Evaluation of UACMM considering real environments (CSMA/CA and TCP flow case)
- Evaluation of UACMM considering methods to determine realistic grid

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