An Access Point Selection Mechanism Based on Cooperation of Access Points and Users Movement

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***Abstract*—Public areas, such as train stations and airports, providing wireless Local Area Network (WLAN) services are increasing and expanding because of the rapid development of WLANs based on IEEE 802.11 standard. Moreover, because of the advances in smartphone tethering technology, portable access points (APs) such as mobile Wi-Fi routers are being utilized more frequently. Consequently, there are increasing circumstances where a user needs to select and connect to one of the many APs. AP selection significantly determines the quality of service of the subsequent communication session. Existing AP selection algorithms consider user movement but not AP movement. We propose an AP selection method that handles both types of movement effectively. Moreover, we show that the proposed method improves the throughput significantly compared to the existing method.**

***Keywords*—mobile AP; AP selection; throughput; AP cooperative; moving;**

I. Introduction

Mobile communication technology continues to develop rapidly and has facilitated the use of laptops and smartphones in public spaces. Wireless local area networks (wireless LANs) based on the IEEE 802.11 standard have also become popular [1]. As a result, the number of public areas, such as train stations and airports, providing wireless LAN services and access points (APs) is increasing. A more recent trend is the popularity of portable APs, such as the mobile Wi-Fi router. A key factor in this trend is recent advancements in smartphone tethering technology. This technology creates an environment in which APs are expected to move frequently. This can result in situations in which multiple APs share the same area. In such a situation, users must select one of the many APs.

To ensure sufficient communication quality, the standard wireless LAN protocol based on IEEE 802.11 usually selects an AP with the highest received signal strength indicator (RSSI) [2]. However, this approach can suffer from uneven AP loading, where a disproportionate number of wireless terminals attempt to connect to the same AP even though alternative APs are under low load. This leads to AP overload and congestion, which greatly reduces communication quality. Selecting an AP with the largest RSSI value may not provide a fair bandwidth allocation or effective bandwidth utilization in environments such as train stations and hotel lobbies [3]. Moreover, multi-rate wireless LAN environments where the transmission rate depends on the distance between the AP and the wireless terminal suffer from what has been referred to as the performance anomaly [4], [5]. This problem decreases the throughput of the AP because the AP is connected to terminals whose transmission rates are extremely low.

The effects of these problems can be reduced by optimizing AP selection. Some studies [6]–[9] have proposed and evaluated many AP selection methods. In particular, [9] proposed an AP selection method based on user cooperation during movement. The method of [9] improves the system throughput (the sum of the throughput of all APs in the system) by cooperative user movement. Thus, the proposed method is based on [9]. Furthermore, various studies [10]–[14] have demonstrated the effectiveness of cooperative user mobility. [10] proposed a traffic control mechanism that considers user collaboration. Moreover, [11] introduced a method to increase the system spectral efficiency of cellular orthogonal frequency-division multiplexing access systems by cooperation of participating users in wireless cellular networks. In addition, [12]–[14] have shown the relationship between communication quality and user route selection. However, previous studies have not considered AP mobility. It is expected that AP mobility will become more common in future. Note that we assume a mobile AP (3G/LTE equipped portable Wi-Fi AP) that can move easily (low cost). We give the following examples of AP movement: (a) Multiple users move with a mobile Wi-Fi router to more convenient places in a conference room (b) In a public space, such as a baseball stadium or concert hall, the network manager moves an AP installed on the ceiling to areas of high temporary-population density (c) After a disaster, an official moves an AP originally installed on a balloon or helicopter to a shelter within the disaster area It is expected that the throughput can be improved considerably by considering the movement of both APs and users.

We propose an AP selection method on the basis of the cooperation of APs and user movement. In addition, we analyze the system throughput and average AP throughput obtained by the proposed method.

This study is organized as follows. Section II describes the performance anomaly and a current AP selection method that is based on user movement. In Section III, we propose an AP selection method that considers both user and AP movement. We evaluate the proposed method in Section IV. Finally, Section V presents conclusions and suggestions for future work.

II. Related work

Here we explain the performance anomaly faced by multi-rate wireless LANs and review an AP selection method that is based on user movement.

A. Performance anomaly in multi-rate environment

The performance anomaly degrades the throughput of all terminals connected to a single AP in a multi-rate environment. The total throughput of terminals connected to the same

TABLE I. Relationship between distance and transmission rate (IEEE 802.11g) [9]

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

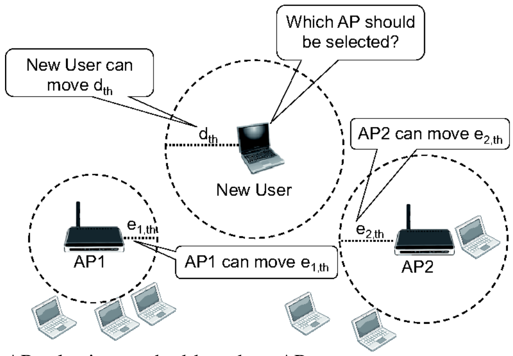

Fig. 1. AP selection method based on AP movement

AP becomes approximately the same as that of the terminal with the lowest transmission rate. This problem is caused by carrier sense multiple access with collision avoidance. In such a wireless LAN environment, each terminal can obtain fair transmission opportunity. In other words, CSMA/CA provides each terminal with equal access to the communication channel. However, in a multi-rate environment, the time for which a terminal occupies the channel depends on its transmission rate. A terminal with a high transmission rate has short channel occupancy time; therefore, the wait time of other terminals is reduced. However, as 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 equal to that of the terminal with the lowest transmission rate. As a result, the throughputs of high transmission rate terminals are decreased.

In a multi-rate environment, the throughput θ_a of the a-th AP can be estimated using Eq. (1) [15]. According to Eq. (1), 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.

$$\theta_a = n_a \left(\sum_{i=1}^{n_a} (b_{i,a})^{-1} \right)^{-1} \quad (1)$$

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

$$\theta_{u,a} = \theta_a (n_a)^{-1} \quad (2)$$

B. AP selection method based on user movement

Here we briefly explain an AP selection method based on user movement [9]. We use this method as a baseline in our comparative evaluations, and we refer to this method as the existing method in our evaluation (Sec. IV). This existing AP selection method maximizes system throughput Θ by cooperating the actions of a new terminal (new user). Θ denotes the sum of the throughput of all APs in the system. The desired action is to move a new user to the AP within an acceptable area (distance) prior to establishing a connection.

A new user has acceptable movement distance d_{th}. Note that a new user attempts to connect to the AP that can maximize Θ. To improve user and system throughput, it is assumed that the new user is willing to move up to acceptable movement distance d_{th}. In [9], one of the stepped transmission rates is selected according to the distance (Table I). In this study, transmission rate is based on [9]. Thus, AP selection is performed as follows. First, the throughput for all APs in the system is calculated assuming the new user moves to an AP within d_{th}. If several APs offer equal maximum throughput, the AP with the shortest distance moved is selected. According to the above consideration, the AP selection method based on user movement is considered a type of optimization problem; i.e., identifying AP a^* that offers the maximum Θ and minimum movement distance $\mathbf{m}^*$ for a new user connection. Note that the user movement distance is never greater than d_{th}.

III. AP selection method based on AP movement

This section describes the proposed AP selection method based on AP movement. For simplicity, we explain the procedure for selecting a single AP.

A. Overview of AP selection method based on AP movement

First, we overview the proposed AP selection method (Fig. 1). The proposed method is an extension of a previously proposed method [9] where movable distances were set for both users and APs. Here 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 i-th AP. The new user and the AP can move freely within the specified distance in the system area. The new user selects an AP to maximize the system throughput Θ. Here Θ has the same meaning as above. The new user moves to a 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, the proposed method selects a combination with the shortest movable distances for the AP and the user. Note that the proposed method is the same as the existing method [9] if $e = 0$.

To define the method as an optimization problem, the objective function and constraints are defined as follows. The objective function maximizes Θ by connecting a new user to the AP. Further, Θ depends on the selected AP a^*, the distance moved by a new user to the AP $\mathbf{m}^*$, and the distance moved by 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 the i-th AP are denoted as d_{th} and $e_{i,th}$, respectively. In addition, the allowable number of users is typically limited by the AP's specifications and policy in real environments; the maximum number of users that can connect to any one AP is denoted as N.

B. 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 using Fig. 2. In Fig. 2, three users are already connected to the AP and a new user attempts to connect to the AP. We assume that each AP and user can obtain the position information (coordinates) of each terminal using certain tools such as GPS. Note that this system assumes movement on a two-dimensional surface; i.e., users and APs exist on the same plane.

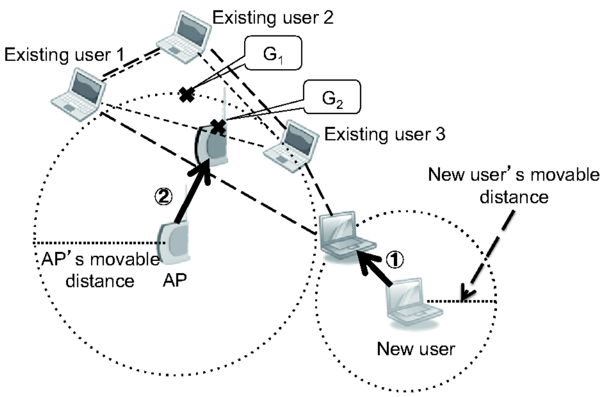

Fig. 2. Determination of communication position of APs and new users

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 movable distance (d_{th}) (Fig. 2 ①). If the new user can move to G_1, the user stops at G_1. If the new user cannot move to G_1, the user stops at the point that minimizes the distance between the user and G_1. 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. Using this procedure, new and existing users can improve throughput after AP movement. Note that 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 two users are connected to the AP, the new user moves to the midpoint of the line connecting the two existing users. Next, the AP moves the gravity point (G_2) of the plane formed by all existing connected users. The AP moves up to its movable distance ($e_{AP,th}$) (Fig. 2 ②). If the AP can move to G_2, it stops at G_2. If the AP cannot move to G_2, it stops at the point that minimizes the distance between itself and G_2. In addition, if there is no existing user, the AP moves to the position of the new 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 upper limit of the movable distance. Thus, users can communicate at higher transmission rates because the distance between the users and AP is reduced. As a result, these procedures maximize the system throughput. Note that the proposed method performs the above procedures for all APs and only one AP with maximum Θ among all APs moves.

IV. Throughput evaluations

Here we present an evaluation of the proposed method using a simulator written in the C programming language. Note that we focus on system throughput and average AP throughput. We evaluate the following two characteristics.

I Impact of movable distance of APs on system throughput performance

II Impact of the number of APs on AP throughput performance

The first characteristic is an indication of the effectiveness of AP movement, which is the key idea of the the proposed method. The second characteristic indicates the effectiveness of AP movement in terms of the throughput of each AP. Note that AP throughput is obtained using Eq. (1), and we use the stepped effective transmission rate b_{eff} as the transmission rate. In addition, 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 they depend on the physical layer. Thus, if we assume the physical layer and MAC, it is expected that the potential effect of cooperative

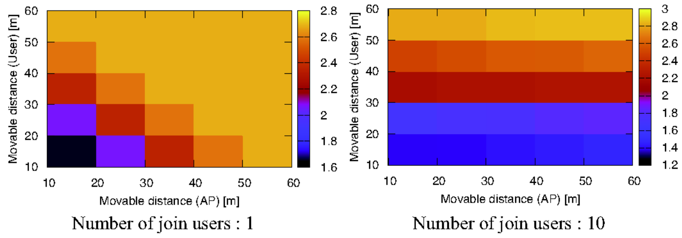

Fig. 3. Relationship between system throughput and movable distance of both the AP and the new user (vs. minimum distance selection method)

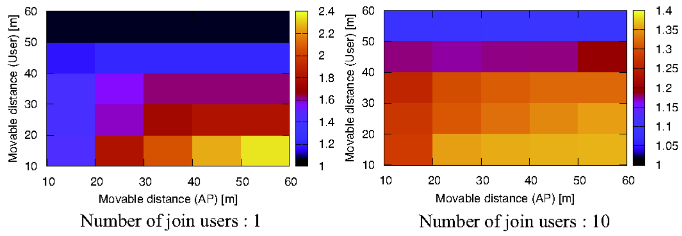

Fig. 4. Relationship between system throughput and movable distance of both the AP and the new user (vs. existing method)

movement will become unclear. Therefore, to achieve our purpose, we do not consider the physical layer and MAC in our evaluations. In future, we will evaluate the proposed method using a network simulator considering more realistic network environment characteristics, such as control overhead and interference between APs.

A. *Movable distance of APs and throughput performance*

First, we evaluate the relationship between the system throughput and the movable distance of an AP. Note that the system throughput is the sum of the throughput of all APs in the network. In a 120m × 120m region, there are APs at (30 m, 60 m) and (90 m, 60 m). This system configuration follows a previous study [9]. In the initial state, only APs are present. Next, users enter the region randomly. All users connect to the AP that offers the highest system throughput. In this situation, the proposed method improves system throughput over the minimum distance selection method and that of [9]. 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 I shows the transmission rate of the user, which has been used in previous studies. This study assumes a saturated UDP flow (i.e., the user always has data to send). In our evaluations, each simulation ran for 30 trials and the results are the averages of the 30 trials. The initial position of the user changed in each simulation.

In the proposed method, both the AP and user move. Thus, in the proposed method, the distance between the AP and user is shorter than in the minimum distance selection method and the method in which only new users move. We have clarified the value by which the proposed method improves the throughput over the minimum distance selection method and the method of [9].

Figure 3 shows the throughput improvement ratio of the proposed method compared to the minimum distance selection method. In the proposed method, the movable distance of both the APs and new users was set to the same value. In Fig. 3, the number of join users is 1 and 10. In Fig. 3, the horizontal axes and vertical axes represent the movable distance of the AP and the new user, respectively. From Fig. 3, if the number of join users is 1, the system throughput of the proposed method is 2.8 times greater than that of the minimum distance selection method when the proposed method can obtain the highest values. In addition, for 10 users, the proposed method

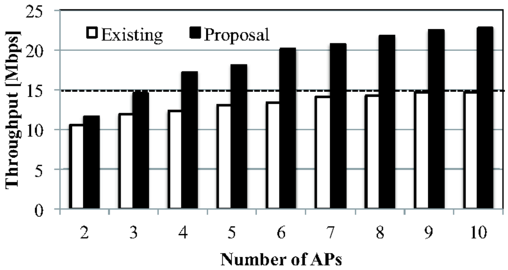

Fig. 5. Throughput performance vs. number of APs in the system (movable distance of AP 10 m, new user 10 m).

can triple system throughput compared to the minimum distance selection method. However, compared to the minimum distance selection method, when the number of join users is high and user movement distance is short, the proposed method does not improve the throughput significantly even if the movable distance of the AP increases. This is because it is difficult to improve throughput by AP movement since many users are distributed widely across the region. Therefore, throughput improvement is best achieved by increasing the movable distance of users rather than that of the AP.

Next, Fig. 4 shows the improvement ratio of system throughput compared to the existing method. For the proposed method, the movable distance of both APs and the new user is changed from 10 m to 60 m. When the number of join users is 1, the proposed method improves system throughput up to 2.4 times that of the existing method. If there are 10 users, the system throughput is improved up to 1.4 times. However, throughput does not improve significantly when the user's movable distance is greater than 60 m. This is because users can move to a position where they can obtain a higher transmission rate by themselves. Therefore, the proposed system can obtain a higher throughput without AP movement. In summary, the proposed method can improve throughput drastically compared to conventional methods.

B. Throughput performance vs. number of APs

Here we evaluate average AP throughput when the number of APs in the system changes. We use a 120 m × 120 m area, as in IV-A. In the initial state, the specified number of APs is set in the region. Users then enter the region randomly until the number of users connected to the AP becomes greater than two. At that point, we calculate the average AP throughput. As the number of users is greater than 2, all APs have connected users and experience the performance anomaly. The transmission rate, traffic type, and the number of trials of the simulation are the same as discussed in IV-A.

Figure 5 shows the average AP throughput for the existing method [9] and the proposed method. The movable distance of users is 10 m for both methods and the movable distance of the AP is 10 m for the proposed method. This aforementioned value indicates that the movable distance of the user and the AP is the shortest. From Fig. 5, the maximum difference between the proposed method and the existing method is approximately 8 Mbps when there are 10 APs. Moreover, with four APs, the proposed method obtains the same average AP throughput as the existing method with 10 APs (dotted line in Fig. 5).

From the above results, it is clear that the proposed method can achieve higher average AP throughput with a fewer number of APs than the existing method.

V. Conclusion

This study has proposed an AP selection method that considers the movement of users and APs and has evaluated its performance. We evaluated the effectiveness of portable APs, such as mobile Wi-Fi routers, to increase the system throughput in multi-rate wireless LAN environments. The proposed method can improve the system throughput drastically compared to the existing method, which moves only the new user. This is because the AP can move to a position where existing users can obtain higher transmission rates. In addition, we compared the system throughput in two environments, i.e., when the users and APs can occupy only particular points and when they can occupy any points in the service area. The results indicate that the difference in destination points has little impact on throughput. Future work will include the following evaluations.

1) Detailed investigations of characteristics
2) Development of a distributed algorithm

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