RSSI-Based Access Points and Channel Selection Method Using Markov Approximation

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***Abstract*—In recent years, a large number of Access Points (APs) have been deployed in public facilities such as stations and airports. These allow users with wireless devices to select their APs from several APs. In general, the communication quality depends on the selected APs, and thus the AP selection is an important technical issue. In this paper, we propose an access-point and channel selection method based on Received Signal Strength Indication (RSSI) value using Markov approximation. In Markov approximation, the system is optimized by individual behavior of users forming a time-reversible continuous-time Markov chain. In the proposed method, to suppress frequent and useless state transitions, users do not select APs with small RSSI values. This reduces the number of state transitions, and thus the time-average objective function value can be increased rapidly. Through simulation experiments, we demonstrate the effectiveness of the proposed method.**

Keywords–Access point selection; channel selection; Markov approximation; RSSI.

I. INTRODUCTION

In recent years, wireless LANs have become increasingly common, and Access Points (APs) have been deployed with very high density [1][2]. In particular, the number of APs deployed in public facilities, such as stations and airports, has increased rapidly. This allows users with wireless devices to select the APs that they can connect from several APs. In general, the communication quality depends on AP selection, and thus the AP selection is an important technical issue.

In the existing AP selection method [1][3], the AP with the highest Received Signal Strength Indicator (RSSI), which is an indicator of the received signal power strength, is selected from the APs within the communication range of each user's device. Because each user selects an AP independently, the user selections are concentrated to the AP with the highest RSSI even when there are other APs nearby. As the load on the AP increases, the throughput decreases, and thus the existing AP selection method does not work well.

In order to solve this problem, other AP selection methods have been considered [4][5][6]. The authors in [6] proposed an AP selection method using Markov approximation. Markov approximation is a recently developed decentralized optimization framework [7]. In Markov approximation, an approximate solution to the optimization problem can be obtained by designing the system to follow a time-reversible continuous-time Markov chain [8][9][10]. Specifically, the time spent in each state in the Markov chain depends on the objective function value, and the aim is to maximize the objective function value in terms of the time-average. The system is designed so that when the system state has the high objective function value, the system stays in this state for a long time. In contrast, when the system stays at the state with the low objective function value, the system quickly transitions from these states. This causes the system to remain in a state with a high objective function values. It was shown in [6] that throughput fairness can be achieved by using Markov approximation to minimize user throughput as an objective function. However, this existing method has the problem that the increases in the objective function value are suppressed because the transitions to states with low objective function values occur frequently.

In this paper, we propose a new AP and channel selection method using Markov approximation based on RSSI values. In our proposed method, each user changes their connections to APs with a high RSSI compared with the current RSSI, and does not change the connection to an AP with a low RSSI value. This makes it possible to suppress the transition to states where the objective function value is low, and to increase the time average value. Through simulation experiments, we demonstrate the effectiveness of the proposed method.

The rest of this paper is organized as follows. In Section II, we explain the system model of this paper. Section III discusses our proposed method. In Section IV, the performance of the proposed method is examined using the results of the simulation experiments. Finally, we conclude the paper in Section V.

II. SYSTEM MODEL

We consider a situation with multiple users and multiple APs, as shown in Figure 1. Let $\mathcal{K}$ be the set of users and $\mathcal{A}$ be the set of deployed APs, respectively. Further, let $\mathcal{C}$ be the set of channels that can be used by each AP. In this case, each AP $a \in \mathcal{A}$ selects one channel from $|\mathcal{C}|$ channels, and each user $k \in \mathcal{K}$ selects one AP from the set $\mathcal{A}$ of APs.

The system state is represented by the combination of the channels selected by each AP and the APs selected by each user. Here, let the $1 \times |\mathcal{A}|$ vector $\boldsymbol{x}$ and $1 \times |\mathcal{K}|$ vector $\boldsymbol{y}$ denote the channels selected by the APs and the APs selected by the users, respectively, where the ith element $x_i \in \{1, 2, \ldots, |C|\}$ of $\boldsymbol{x}$ is the channel selected by AP i and the jth element $y_j \in \{1, 2, \ldots, |\mathcal{A}|\}$ of $\boldsymbol{y}$ is the AP selected by user j. The system state is represented as $(\boldsymbol{x}, \boldsymbol{y})$, and the set $\mathcal{Z}(t)$ of feasible

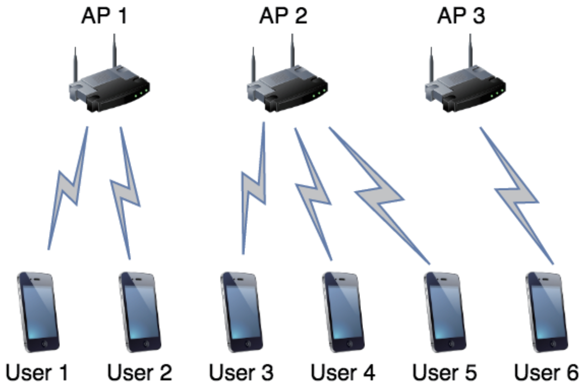


Figure 1. System model ($|\mathcal{K}| = 6, |\mathcal{A}| = 3$).

system states at time t can be represented as follows:

$$\begin{aligned}\mathcal{Z}(t) \quad = \quad & \{(\boldsymbol{x}, \boldsymbol{y}) \mid x_i \in [1, |\mathcal{C}|],\ y_j \in [1, |\mathcal{A}|] \\ & i = 1, 2, \ldots, |\mathcal{A}|,\ j = 1, 2, \ldots, |\mathcal{K}|\}. \quad (1)\end{aligned}$$

In the following, we call a feasible state $z \in \mathcal{Z}(t)$ a *strategy*.

When multiple users select the same AP, it is assumed that frequency resources can be used evenly by time division multiplexing. Therefore, when strategy z is adopted, the throughput $u_k(z)$ for each user k is defined as

$$u_k(z) = m_{k,a}/N_c(z), \tag{2}$$

where $m_{k,a}$ is the throughput that can be achieved when only user k is connected to AP a, and $N_c(z)$ is the total number of users connected to the same channel $c \in \mathcal{C}$ used as user k. Note that this multiplexing assumption is simple, and thus we will tackle to the more realistic situation.

In order to achieve the throughput fairness, we consider the problem of maximizing the *utility* $\min_{k\in\mathcal{K}} u_k(z)$, which is the minimum throughput among all users in $\mathcal{K}$. The problem of maximizing the utility at time t can be formulated as

$$\max_{z\in\mathcal{Z}(t)} \{\min_{k\in\mathcal{K}} u_k(z)\}. \tag{3}$$

III. RSSI-BASED AP AND CHANNEL SELECTION METHOD USING MARKOV APPROXIMATION

We first explain about the Markov approximation, and then describe the details of our proposed method.

A. Markov approximation

This section assumes a static situation where there is no increase or decrease in the number of users. In such a static situation with $\Phi_z = \min_{k\in\mathcal{K}} u_k(z)$ as an objective function, an approximate solution can be obtained by solving the following problem [7].

$$\max_{\boldsymbol{p}(t)\leq 0} \quad \sum_{z\in\mathcal{Z}(t)} p_z \Phi_z - \frac{1}{\beta} \sum_{z\in\mathcal{Z}(t)} p_z \log p_z, \tag{4}$$

$$\text{subject to} \quad \sum_{z\in\mathcal{Z}(t)} p_z = 1, \tag{5}$$

where p_z is the time ratio at which the strategy $z \in \mathcal{Z}(t)$ is adopted, and $\boldsymbol{p}(t)$ is a $1 \times |\mathcal{Z}(t)|$ vector $(p_1, p_2, \cdots, p_{|\mathcal{Z}(t)|})$. Furthermore, β is a parameter for controlling the accuracy of the approximation, which improves as β increases. Because this problem is a nonlinear programming problem, the optimal solution p_z^* can be obtained by solving the following problem based on the KKT (Karush-Kuhn-Tucker) condition.

$$\Phi_z - \frac{1}{\beta} \log p_z^* - \frac{1}{\beta} + \eta = 0, \qquad \forall z \in \mathcal{Z}(t) \tag{6}$$

$$\sum_{z\in\mathcal{Z}(t)} p_z^* = 1, \tag{7}$$

$$\eta \geq 0, \tag{8}$$

where η is a Lagrange multiplier.

The solution p_z^* ($z \in \mathcal{Z}(t)$) to the above problem is given by

$$p_z^* = \frac{\exp(\beta\Phi_z)}{\sum_{z'\in\mathcal{Z}(t)} \exp(\beta\Phi_{z'})}. \tag{9}$$

Note that this solution p_z^* also represents the steady-state probability of a time-reversible continuous-time Markov chain on $\mathcal{Z}(t)$ [7]. Therefore, if the APs and the users follow the Markov chain in which the steady-state probability is p_z^*, we obtain an approximate solution to the original problem.

It is known that a continuous-time Markov chain is time-reversible when the following local equilibrium equations for all strategies z, z' in $\mathcal{Z}(t)$ are satisfied:

$$p_z^* q_{z,z'} = p_{z'}^* q_{z',z}, \tag{10}$$

where $q_{z,z'}$ is the transition rate from strategy z to strategy z'. Substituting (1) into the above equation yields the following equation:

$$\exp(\beta\Phi_z) q_{z,z'} = \exp(\beta\Phi_{z'}) q_{z',z} \tag{11}$$

To achieve a time-reversible Markov chain, the transition rate $q_{z,z'}$ is set to be $q_{z,z'} = \alpha(t)/\exp(\beta\Phi_z)$, where $\alpha(t)$ is a parameter that controls the transition rate. In [6], we evaluated the performance in a static situation, and showed that an accurate solution with high accuracy can be obtained by fixing $\alpha(t)$ to be an appropriate value.

B. Details of our proposed method

In our proposed method, each AP and each user select a channel and an AP according to the Markov chain on $\mathcal{Z}(t)$, respectively. Figure 2 presents a flowchart of our proposed method. Each AP $a \in \mathcal{A}$ chooses a random number r according to the exponential distribution with parameter $\lambda(t) = \alpha(t)(|\mathcal{C}| - 1)/\exp(\beta\Phi_z)$. On the other hand, each user $k \in \mathcal{K}$ chooses a random number r according to the exponential distribution of $\lambda(t) = \alpha(t)(|\mathcal{A}_k| - 1)/\exp(\beta\Phi_z)$, where $\mathcal{A}_k$ represents the set of APs with the high RSSI values for user $k \in \mathcal{K}$. After choosing the random number r, all APs and users start counting down.

When the count for either an AP or a user falls below 0, the strategy is changed according to the following procedure. If the count for AP $a \in \mathcal{A}$ is less than 0, then one channel is randomly selected from the channels in $\mathcal{C} \setminus \{c\}$, and AP a switches to the selected channel. On the other hand, if the count for a user $k \in \mathcal{K}$ is less than 0, then one AP a is randomly selected from the set $\mathcal{A}_k$ of APs with the high RSSI values, and then switches to AP a. When switching is completed, the APs and users are notified of the new utility value. Specifically, if the strategy is changed to z_{new} by switching, then the utility is

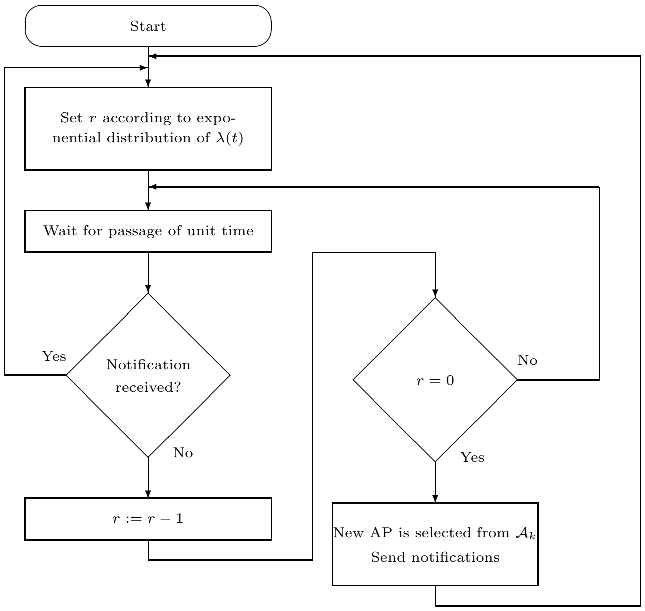


Figure 2. Flowchart of AP k in our proposed method.

updated to $\Phi_{z_{\mathrm{new}}}$. After that, the APs and users that received the notification of a strategy change cancel their countdown and reset the random number r.

In our proposed method, $\alpha(t)$ is set as follows:

$$\alpha(t) = \frac{\gamma \cdot \exp(\beta M(t))}{|\mathcal{A}|(|\mathcal{C}| - 1) + \sum_{k \in \mathcal{K}}(|\mathcal{A}_k| - 1)}, \tag{12}$$

where $\gamma > 0$, and $M(t)$ is the maximum utility from time 0 to time t. Therefore, if $\Phi_z > M(t)$, $M(t)$ is updated to $M(t) := \Phi_z$.

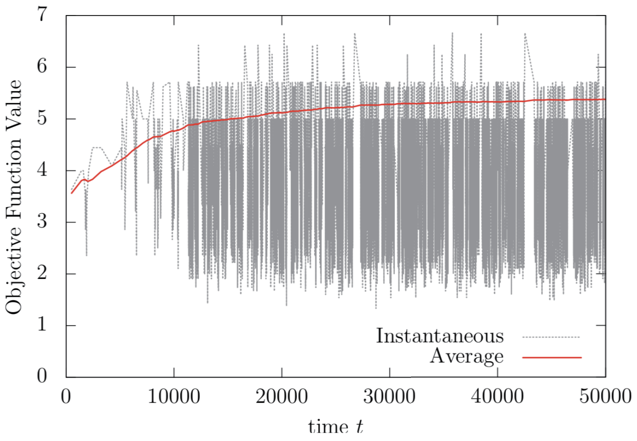
IV. PERFORMANCE EVALUATION

We first describe the simulation model, and then present the simulation results and discuss the effectiveness of our proposed method.

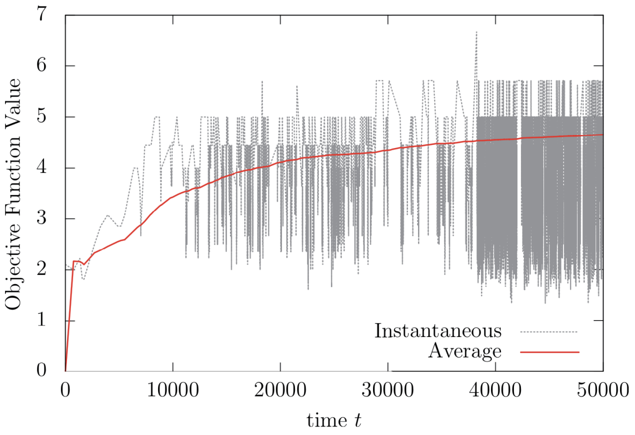
A. *Simulation model*

The number of users is $|\mathcal{K}| = 50$, the number of APs is $|\mathcal{A}| = 20$, and the number of channels is $|\mathcal{C}| = 10$. The maximum throughput $m_{k,a}$ is chosen randomly from $\{40, 45, 50\}$. In addition, the parameter γ controlling the transition rate is set to be 0.01. Unless otherwise specified, the set of APs with the high RSSI values for user k is represented by $\mathcal{A}_k = \{a \mid m_{k,a} = 50, a \in \mathcal{A}\}$. Unless otherwise stated, we set β the moderate value, i.e., $\beta = 3$, because for large β, the accuracy of the approximation improves but the number of state transitions is very large.

We compare the performance of our proposed method with that of the existing AP selection method using Markov approximation in [6]. In the existing AP selection method, the connected AP is selected from $\mathcal{A} \setminus \{a\}$ regardless of the RSSI value. When $\mathcal{A}_k = \mathcal{A}$ in the proposed method, the behavior of the proposed method is equivalent to that of the existing method.



(a) Our proposed method.



(b) Existing method.

Figure 3. Objective function value as a function of the elapsed time t.

B. *Results*

Figures 3(a) and 3(b) show the objective function value of our proposed method and the existing method as a function of the elapsed time t, respectively. The instantaneous value in Figure 3 represents the value of the objective function $\Phi(t)$ at time t, and the average value represents the time average value of the objective function value $\bar{\Phi}(t)$, which is defined by the following equation.

$$\bar{\Phi}(t) = \frac{1}{t} \int_0^t \Phi(t) dt. \tag{13}$$

From Figure 3(b), because the existing method does not consider the RSSI value, the system state transitions to states with small objective function values and stays in those states for a long time. Therefore, the time-average $\bar{\Phi}(t)$ of the objective function value increases slowly. On the other hand, as we can see from Figure 3(a), the time-average $\bar{\Phi}(t)$ of the objective function increases more rapidly compared with that of the existing method. This result indicates that considering the RSSI values suppress transitions to states with low objective function values.

Next, we examine the effects of differences in the set of APs $\mathcal{A}_k$ with high RSSI values. Figure 4 shows the time-average objective function values $\bar{\Phi}(t)$ for $\mathcal{A}_k = \{a \mid m_{k,a} =$

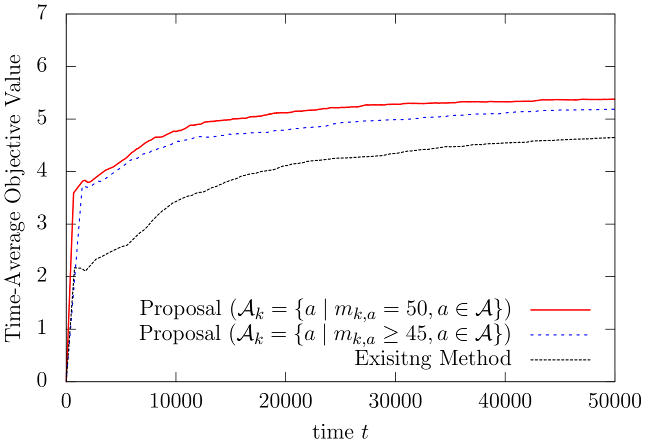


Figure 4. Time-average objective function value as a function of the elapsed time t.

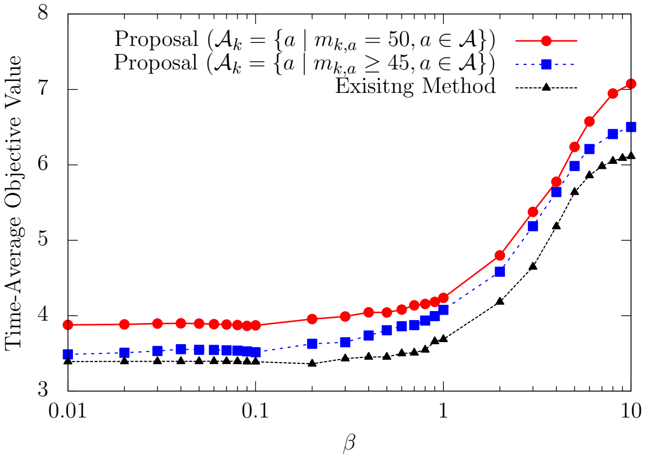


Figure 5. Time-average objective function value as a function of the parameter β.

$50, a \in \mathcal{A}\}$ and $\mathcal{A}_k = \{a \mid m_{k,a} \leq 45, a \in \mathcal{A}\}$. From this figure, it can be seen that by not selecting the AP with the lowest RSSI value ($m_{k,a} = 40$), the objective function value increases rapidly.

Figure 5 shows the time-average objective function value $\bar{\Phi}(t)$ as a function of the parameter β that controls the approximation accuracy. Note that each point represents the value $\bar{\Phi}(50,000)$, i.e., the time-average value when 50,000 time units have passed. From Figure 5, the value of the objective function value increases monotonically as the parameter β increases. This is because increasing parameter β also increases the accuracy of the approximation increases, so that the objective function value also increases. In addition, the objective function value for the proposed method is larger than that for the existing method for all β, and thus confirming the effectiveness of considering the RSSI value.

V. CONCLUSION

In this paper, we have proposed an AP selection method using Markov approximation by considering RSSI values. The performance of the proposed method was compared with that of the existing method using simulation experiments, and it was shown that the rate of increase of the objective function value could be improved. In this paper, we have considered a static environment with a fixed number of users. In reality, AP selection occurs in a dynamic environment where the number of users changes. Therefore, a topic for future research is evaluating the performance of the proposed method in a dynamic environment.

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