An access point selection algorithm for heterogeneous stations

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Abstract
In wireless LAN technology, access point selection at each station is a critical problem in order to obtain satisfactory throughputs. The current protocol for access point selection is based on received signal strength, and a concentration of stations causes a degradation of the entire wireless network. To avoid the problem, various algorithms have been proposed.

In the present paper, we first verify performances of known access point selection algorithms in the wireless LAN environment such that there are two types of stations communicating with TCP and UDP. Next, we propose an access point selection algorithm with QoS control for the heterogeneous wireless LAN environment. In the algorithm, each station uses different algorithms according to types of communication protocols. We finally show experimental results of the proposed algorithm and known algorithms, and verify effectiveness of the proposed algorithm.

Keywords: wireless LAN, access point selection

1 Introduction
In recent years, IEEE 802.11 wireless LAN technology has spread widely, enabling individuals to connect to the Internet from almost everywhere. The wireless LAN environment consists of access points (APs) and stations, and each station selects an available AP in order to connect to the Internet without any centralized control. For the wireless LAN environment, the spread of technology has made multiple APs available for stations. Thus, the AP selection for each station is a critical problem for obtaining satisfactory throughputs.

In current wireless LAN technology, an algorithm, which is called Received Signal Strength (RSS)[3], is used for AP selection. In RSS, each station selects one of APs with the maximum signal strength. However, RSS may cause a concentration of connections to one of APs. Since the throughput of each station decreases in proportion to the number of stations connected to the same AP, the concentration causes the degradation of the entire wireless network.

Therefore, various centralized and decentralized AP selection algorithms[1, 2, 4, 6] have been proposed in order to avoid concentration of stations. However, the algorithms do not assume multi-protocol environment such that two types of stations communicating with TCP and UDP exist. Thus, the algorithms may not achieve efficient AP selection in the environment.

In the present paper, we first verify performances of the known AP selection algorithms using QualNet[7], which is one of the widely used network simulators. The simulation results show that throughputs of TCP stations are inferior to those of UDP stations using every known AP selection algorithms.

We next propose an AP selection algorithm with QoS control for the heterogeneous wireless LAN environment. In the algorithm, each station uses different algorithms according to types of communication protocols. Each TCP station selects one of APs using signal strength and the number of UDP stations connected to the same AP. On the other hand, each UDP station selects one of APs using MLT[2], which is one of the known algorithms.

We finally implement our proposed algorithm in the simulation environment and compare throughputs of the proposed algorithm and the known algorithms. The experimental results show that minimum throughputs of TCP stations of the proposed algorithm are superior to those of the known algorithms. Since the minimum throughput of TCP stations is lower than the minimum throughput of UDP stations, the result implies that the proposed algorithm achieves the better minimum throughput than all known algorithms.
2 Preliminaries

2.1 Communication model

We first introduce the communication model and throughputs used in the paper. We assume that there are $n$ stations and $m$ APs in the wireless LAN environment, and $S = \{s_0, s_1, \ldots, s_{n-1}\}$ and $A = \{a_0, a_1, \ldots, a_{m-1}\}$ denote sets of stations and APs, respectively.

For each pair of station $s_i$ and AP $a_j$, a packet error rate $P_{i,j}$ is defined. The packet error rate $P_{i,j}$ represents the packet error rate for connection in the wireless LAN environment. In the above expression, $P_{i,j}$ is the maximum packet error rate, to any station. In other words, each station knows these values for all of the APs.

Using the packet error rate, we estimate $\theta_{i,j}$, which denotes a throughput between station $s_i$ and AP $a_j$, according to the IEEE 802.11 MAC mechanism. Let $N_j$ be the number of stations that are connected to AP $a_j$. Then, the throughput $\theta_{i,j}$ is given by the following expression [2].

$$\theta_{i,j} = \frac{Data \cdot (1 - P_{i,j})}{t_T \cdot N_j}$$  \hspace{1cm} (1)

In the above expression, $t_T$ and $Data$ denote the transmission time and the size of the transmitted packet, respectively. Since $t_T$ is a constant that depends on the wireless LAN environment, the above expression can be modified to the following throughput $\theta_{i,j}$ when all of the packets are the same size.

$$\theta_{i,j} = \alpha \times \frac{1 - P_{i,j}}{N_j}$$  \hspace{1cm} (2)

In the above expression, $\alpha$ is a constant that depends on the wireless LAN environment. The expression (2) implies that the throughput $\theta_{i,j}$ is linearly dependent on $\frac{1 - P_{i,j}}{N_j}$.

We also employ the following assumptions in the communication model for the wireless LAN environment.

- Each station knows the packet error rates for all of the APs.
- Each AP knows the number of connected stations and the packet error rates of all connected stations. Thus, each AP can compute the sum of the throughputs of the connected stations as well as the maximum packet error rate among the connected stations.
- Each AP can send the above three values, which are the number of connected stations, the sum of the throughputs and the maximum packet error rate, to any station. In other words, each station knows these values for all of the APs.

2.2 AP selection problem

In this subsection, we formally define the AP selection problem. Input of the problem is a set of stations $S = \{s_0, s_1, \ldots, s_{n-1}\}$ and a set of APs $A = \{a_0, a_1, \ldots, a_{m-1}\}$. For each pair of station $s_i$ and AP $a_j$, packet error rate $P_{i,j}$ is also given.

Output of the problem is a set of $n$ pairs of a station and AP, such as $\{(s_0, a_{j_0}), (s_1, a_{j_1}), \ldots, (s_{n-1}, a_{j_{n-1}})\}$. Each pair $(s_i, a_{j_i})$ implies that station $s_i$ is connected to AP $a_{j_i}$. In other words, each station selects AP $a_{j_i}$ for connection in the wireless LAN environment. In this case, $\theta_i$, which denotes the throughput between $s_i$ and $a_{j_i}$, is given as follows.

$$\theta_i = \alpha \times \frac{1 - P_{i,j_i}}{N_{j_i}}$$

For the above output, we define the following two objective functions.

(1) Average throughput: The average throughput $T_{avg}$ denotes the average of throughputs of the stations. $T_{avg}$ is defined for an output of AP selection as follows.

$$T_{avg} = \frac{1}{n} \sum_{i=0}^{n-1} \theta_i = \frac{\alpha}{n} \sum_{i=0}^{n-1} \frac{1 - P_{i,j_i}}{N_{j_i}}$$

(2) Minimum throughput: The minimum throughput $T_{min}$ denotes the minimum throughput among those of the stations. $T_{min}$ is also defined as follows.

$$T_{min} = \min \{\theta_i \mid 0 \leq i \leq n - 1\} = \min \left\{ \alpha \times \frac{1 - P_{i,j_i}}{N_{j_i}} \mid 0 \leq i \leq n - 1 \right\}$$

2.3 Known AP selection algorithms

In this subsection, we briefly introduce four known AP selection algorithms.

2.3.1 Received Signal Strength (RSS)
The Received Signal Strength (RSS) is a simple and conventional AP selection algorithm. Each station selects one of available APs according to signal strength. An outline of the algorithm on each station $s_i$ is given below.

**Step 1:** For each AP $a_j$ ($0 \leq j \leq m - 1$), compute $r_{ss_j} = 1 - P_{i,j}$.

**Step 2:** Select AP $a_{j_i}$ such that $r_{ss_{j_i}} = \max \{r_{ss_j} \mid 0 \leq j \leq m - 1\}$.

2.3.2 Maximizing Local Throughput (MLT)
The Maximizing Local Throughput (MLT) [2] is an AP selection algorithm based on a feature of throughput in the wireless LAN environment. In the wireless LAN environment, the throughput between station $s_i$ and AP $a_j$ depends linearly on the value $\frac{1 - P_{i,j}}{N_j}$, where...
$P_{i,j}$ is the packet error rate between $s_i$ and $a_j$, and $N_j$ is the number of stations connected to AP $a_j$. In MLT, each station selects one of the available APs according to the above value. An outline of MLT on each station $s_i$ is given below.

**Step 1:** Receive $N_j$ from each AP $a_j$ ($0 \leq j \leq m-1$).

**Step 2:** For each AP $a_j$ ($0 \leq j \leq m-1$), set $N_j = N_j + 1$ in case that $s_i$ is not connected to $a_j$, and then, compute the following value $mlt_j$.

$$mlt_j = \frac{1 - P_{i,j}}{N_j}$$

**Step 3:** Select AP $a_j$, such that $mlt_j = \max\{mlt_j \mid 0 \leq j \leq m-1\}$.

### 2.3.3 Maximizing Total Throughput (MTT)

The Maximizing Total Throughput (MTT)[1] is an AP selection algorithm for maximizing the average throughput of APs. In MTT, each station selects an AP that maximizes the amount of increase in the throughput. The amount of increase in the throughput is obtained as follows.

We assume that station $s_i$ is not connected to AP $a_j$. We also assume that $N_j$ is the number of stations that are connected to AP $a_j$, and $S_j$ is a set of stations connected to AP $a_j$. Then, the sum of throughputs of stations connected AP $a_j$, which is denoted by $\Theta_j$, is expressed as follows.

$$\Theta_j = \sum_{i \in S_j} (1 - P_{i,j})$$

We next compute the sum of the throughputs for the case in which station $s_i$ is connected to AP $a_j$. The sum of throughputs of stations connected to AP $a_j$ is given as follows.

$$\Theta_j \times N_j + (1 - P_{i,j})$$

$$N_j + 1$$

Therefore, the amount of increase in the throughput, which is denoted by $mtt_j$, is expressed as follows.

$$mtt_j = \frac{\Theta_j \times N_j + (1 - P_{i,j}) - \Theta_j}{N_j + 1}$$

An outline of MTT on each station $s_i$ is given below.

**Step 1:** From each AP $a_j$ ($0 \leq j \leq m-1$), obtain $N_j$ and $\Theta_j$.

**Step 2:** For each AP $a_j$ ($0 \leq j \leq m-1$), set $N_j = N_j + 1$ if $s_i$ is not connected to $a_j$, and then, compute the following value of $mtt_j$.

$$mtt_j = \frac{(1 - P_{i,j}) - \Theta_j}{N_j + 1}$$

**Step 3:** Select AP $a_j$ such that $mtt_j = \max\{mtt_j \mid 0 \leq j \leq m-1\}$.

### 2.3.4 Increasing Minimum Throughput (IMT)

The Increasing Minimum Throughput (IMT)[1] is an AP selection algorithm for maximizing the minimum throughput of stations. In IMT, each station selects one of APs such that the minimum throughput is the maximum. The minimum throughput for AP $a_j$ is obtained as follows.

We assume that $P_{max,j}$ denotes the received maximum packet error rate from each AP $a_j$, and $S_j$ denotes a set of stations connected to AP $a_j$. Then, $P_{max,j}$ is given by the following expression.

$$P_{max,j} = \max\{P_{max,j} \mid s_k \in S_j\}$$

Next, the minimum throughput $int_j$ is computed for AP $a_j$ using $P_{max,j}$ and $P_{i,j}$. The minimum throughput $int_j$ is expressed as follows.

$$int_j = \frac{1 - \max\{P_{max,j} \mid P_{i,j}\}}{N_j}$$

An outline of IMT on each station $s_i$ is given below.

**Step 1:** From each AP $a_j$ ($0 \leq j \leq m-1$), obtain $N_j$ and $P_{max,j}$.

**Step 2:** For each AP $a_j$ ($0 \leq j \leq m-1$), set $N_j = N_j + 1$ if $s_i$ is not connected to $a_j$, and then, compute the following value of $int_j$.

$$int_j = \frac{1 - \max\{P_{max,j} \mid P_{i,j}\}}{N_j}$$

**Step 3:** Select AP $a_j$, such that $int_j = \max\{int_j \mid 0 \leq j \leq m-1\}$.

### 3 Simulation results of known algorithms for heterogeneous stations

In this section, we describe experimental results of the known algorithms for heterogeneous stations. We show experimental results of the known algorithms on QualNet 4.0[7], and then, we discuss performances of the known algorithms from the experimental results.

#### 3.1 Simulation environment

**3.1.1 Simulation model**

In the simulation, we assume that there are 4 APs and 40 stations in a 2D plain, which is shown in Figure 1. We first assume a $50m \times 50m$ square area, and each AP is located at the middle point of each side. We also assume that 40 stations are randomly located in the $30m \times 30m$ gray area shown in Figure 1. The allocation provides a biased situation so that several stations are close to two APs.
3.1.2 Simulation parameters

We execute the simulation using communication parameters that are shown in Table 1. In addition, Table 2 shows parameters of applications used in the simulation. In the simulation, we use two traffic generation programs. One is a program called the File Transfer Protocol (FTP), and the program simulates communication with TCP. The other is a program called Constant Bit Rate (CBR), and the program simulates communication with UDP.

Table 1: Communication parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation time</td>
<td>130sec</td>
</tr>
<tr>
<td>Wireless link</td>
<td>IEEE 802.11b 11Mbps</td>
</tr>
<tr>
<td>Wired link</td>
<td>IEEE 802.3 10Gbps</td>
</tr>
<tr>
<td>IP</td>
<td>IPv4</td>
</tr>
<tr>
<td>Routing protocol</td>
<td>bellman ford</td>
</tr>
<tr>
<td>TCP</td>
<td>TCP Sack</td>
</tr>
</tbody>
</table>

3.1.3 Simulation scenarios

Two scenarios of the simulation are as follows. In Scenario 1, all stations communicate with TCP. In the Scenario 2, there are two types of stations communicating with TCP and UDP.

- Scenario 1: 40 FTP stations
- Scenario 2: 20 FTP stations and 20 CBR stations

3.2 Experimental results

In this subsection, we introduce experimental results for each scenario. In each simulation, we randomly generate 100 locations of stations. Then, we execute the simulation for each location. In each graph, the vertical axis indicates throughput (kbps) obtained from communication with the applications. In addition, the horizontal axis indicates locations of stations.

3.2.1 Scenario 1

Figures 2 and 3 are results of the simulation in Scenario 1 for average and minimum throughputs, respectively.

In Figure 2, average throughputs of MLT and IMT are inferior to those of RSS. In addition, average throughputs of MTT are the same or less than those of RSS.

In Figure 3, minimum throughputs of MLT and IMT are almost the same as those of the other two algorithms.

3.2.2 Scenario 2

Figures 4 and 5 are results of the simulation in Scenario 2 for average and minimum throughputs, respectively.

In Figure 4, average throughputs of MLT, MTT, and IMT are the same or less than those of RSS in both results as well as the results in Scenario 1. Then, average throughputs of TCP stations are inferior to those of UDP stations for every algorithms.

In Figure 5, minimum throughputs of MLT and IMT are almost the same as those of the other two algorithms in both results as well as the results in Scenario 1. Then, minimum throughputs of TCP stations are largely inferior to those of UDP stations for every algorithms. Therefore, the minimum throughputs of TCP stations are the minimum throughputs of all stations.
3.3 Discussion

In the results of the simulation, average throughputs of MLT, MTT, and IMT are the same or less than those of RSS in both scenario, and minimum throughputs of MLT and IMT are also almost the same as those of RSS and MTT. In addition, average and minimum throughputs of TCP stations are largely inferior to those of UDP stations for every algorithms.

The result implies that throughputs of TCP stations are influenced by the packet error rate and the number of UDP stations connected to the same AP. The result also implies that throughputs of UDP stations are influenced by the number of UDP stations connected to the same AP.

Since the difference between communication with TCP and UDP is not considered in the known algorithms, throughputs of TCP stations are largely inferior to those of UDP stations.

4 Proposed algorithm

In this section, we propose an AP selection algorithm in order to avoid degradation of throughputs of TCP stations. In our algorithm, each station uses different algorithms according to types of communication protocols.

4.1 AP selection algorithm for TCP station

In the wireless LAN environment, the transmission data rate is decreased by congestion control of TCP. In other words, throughputs of TCP stations are largely influenced by signal strength and the number of UDP stations connected to the same AP. To increase throughputs of TCP stations, each TCP station needs to select an AP such that its signal strength is strong and the number of UDP stations is small.

Therefore, we use the number of UDP stations connected to the same AP as a parameter. Let $U_j$ be the number of UDP stations connected to the AP $a_j$. In the first step of the algorithm, each station $s_i$ receives $U_j$ and computes the received signal strength for each AP $a_j$. Next, each station decide two APs, which are APs $a_{j_1}$ and $a_{j_2}$. The AP $a_{j_1}$ is an AP with the maximum signal strength, and the AP $a_{j_2}$ is an AP with the second signal strength. Then, each station compares $U_{j_1}$ with $U_{j_2}$ for the APs, and selects the AP such that the number of UDP stations is smaller.

We now summarize the algorithm on each station $s_i$. The algorithm consists of the following four steps.

**Step 1:** For each AP $a_j$ $(0 \leq j \leq m - 1)$, receive $U_j$ and compute $rss_j = 1 - P_{i,j}$.

**Step 2:** Compute $rss_{j_1} = \max\{rss_j \mid 0 \leq j \leq m - 1\}$ and $rss_{j_2} = \max\{rss_j \mid 0 \leq j \leq m - 1, rss_j \neq rss_{j_1}\}$.

**Step 3:** For two APs, $a_{j_1}$ and AP $a_{j_2}$, compare $U_{j_1}$ with $U_{j_2}$.

**Step 4:** Select AP $a_{j_2}$ in case that $U_{j_1} \leq U_{j_2}$, otherwise select AP $a_{j_1}$.

The algorithm causes a concentration of connections of TCP stations to one of APs such that the number of UDP stations is small.
4.2 AP selection algorithm for UDP station

In the communication with UDP, a sender of the communication always transmits packets to stations at the same data rate. When the number of stations connected to the same AP increases, throughputs of UDP stations are degraded by packet loss in a buffer of AP. In addition, throughputs of TCP stations connected to the same AP are also degraded. To increase throughputs of UDP stations, each UDP station needs to select an AP such that the number of UDP stations is small. UDP stations also need to avoid selecting an AP such that the large number of TCP stations are connected, in order to decrease an effect of throughputs of TCP stations.

As a result of the above discussion, we use MLT as AP selection algorithm for UDP station. In [5], it is shown that the numbers of stations connected to APs become nearly equal using MLT. In addition, connections of TCP stations concentrate to some of APs, because the AP selection algorithm for TCP station is based on RSS. Thus, UDP stations can avoid connecting to an AP such the large number of TCP stations are connected.

5 Simulation results of the proposed algorithm for heterogeneous stations

In this section, we show experimental results of the proposed algorithm for heterogeneous stations. Simulation environment is the same as the simulation in Section 3. We compare the results of the proposed algorithm with those of the known algorithms, and discuss effectiveness of the proposed algorithm. In the experimental results, we omit the results in Scenario 1, because throughputs of the proposed algorithm in Scenario 1 is the same as those of RSS.

5.1 Experimental results

Figures 6 and 7 are results of the simulation in Scenario 2 for average and minimum throughputs, respectively.

In Figure 6, average throughputs of UDP stations of the proposed algorithm are inferior to those of all known algorithms. However, average throughputs of TCP stations of the proposed algorithm are superior to those of MLT and IMT.

In Figure 7, minimum throughputs of UDP stations of the proposed algorithm are inferior to those of all known algorithms in most locations. However, minimum throughputs of TCP stations of the proposed algorithm are superior to those of all known algorithms in most locations.

Figure 6: Average throughputs for the proposed algorithm

Figure 7: Minimum throughputs for the proposed algorithm

5.2 Discussion

In the results of the simulation, average throughputs of TCP stations of the proposed algorithm are almost the same as those of RSS and MTT, and average throughputs of UDP stations of the proposed algorithm are inferior to those of all known algorithms. However, minimum throughputs of TCP stations of the proposed algorithm are superior to those of all known algorithms. Since the minimum throughput of TCP
stations is lower than the minimum throughput of UDP stations, the result implies that the proposed algorithm achieves the better minimum throughput than all known algorithms.

6 Conclusions

In the paper, we first verified performances of the known AP selection algorithms in the wireless LAN environment such that there are two types of stations communicating with TCP and UDP. The simulation results show that throughputs of TCP stations are inferior to those of UDP stations using every known AP selection algorithms.

We next proposed an AP selection algorithm with QoS control for the heterogeneous wireless LAN environment, and compared throughputs between the proposed algorithm and the known algorithms. The experimental results show that minimum throughputs of TCP stations of the proposed algorithm are superior to those of the known algorithms. The fact implies that the proposed algorithm achieves the better minimum throughput than all known algorithms.

As our future research, we will consider AP selection algorithms that guarantee QoS for UDP stations and increase throughputs of TCP stations.

References


