Decentralized Access Point Selection Architecture for Wireless LANs -Deployability and Robustness-

Yutaka FUKUDA
Information Science Center,
Kyushu Institute of Technology.
Address: Kawazu 680-4, Iizuka, 820-8502 Japan.
Email: fukuda@isc.kyutech.ac.jp

Yuji OIE
Dept. of Computer Science and Electronics,
Kyushu Institute of Technology.
Address: Kawazu 680-4, Iizuka, 820-8502 Japan.
Email: oie@cse.kyutech.ac.jp

Abstract— **According to the spread of wireless LAN, multiple access points (APs) will be much more likely to be available there for Stations (STAs), which can roam from one AP to another by some rule. Consequently, following significant issue can arise in those cases: how to select an appropriate AP among available APs. In the existing architecture, the received signal strength is usually used to select an AP. However, such AP selection strategy causes the concentration of STAs to specific APs and STAs cannot use the resource of wireless LAN effectively. Hence, we proposed decentralized AP selection strategies, and showed that proposed strategies can achieve an efficient and fair share of wireless access resources [7]. Then, we here examine deployability and robustness of our decentralized architecture from a practical viewpoint. The proposed architecture should be deployed without hurting the performance of the common existing architecture currently widely deployed. Therefore, the deployability of our architecture is examined in this respect. Furthermore, in addition to static characteristics, the dynamic behavior of the proposed architecture is studied to examine its robustness against some dynamic changes of situation due to AP breakdown and bursty arrivals of STAs. Our simulation results show that the proposed architecture has excellent features in terms of both of deployability and robustness.**

I. Introduction

With the spread of wireless LAN [1], [2], the number of stations (STAs) connected with the wireless LAN also increases. STAs share the communication resource provided by APs in order to communicate with exterior network. Therefore, multiple APs are required to serve many STAs and to improve the transmission capacity in the wireless LAN. In fact, IEEE 802.11 wireless LAN can extend the communication range through the multiple APs. Consequently, the following significant issue can arise in those cases: how to select an appropriate AP among available APs.

In the existing architecture, the received signal strength is usually used to select an AP. However, such AP selection strategy causes the concentration of STAs to specific APs: many STAs may associate with only a few APs because their signal strengths measured by the STAs are strong; while only a few STAs may associate with the remaining APs. This results in imbalanced traffic load on APs in the wireless LAN, thereby degrading the fairness in STA throughput and harming an efficient use of the wireless LAN resource. Indeed, many studies have shown the traffic characteristics and user behavior of wireless LAN [3], [4], [5], [6], and they report that traffic load is often distributed quite unevenly among APs.

In order to solve this issue, we have proposed the decentralized AP selection architecture [7], which is simple and scalable compared with the centralized architecture. In the proposed decentralized architecture, each STA selects its AP based upon the algorithm which optimizes its own throughput locally. Furthermore, each STA dynamically changes its accessing AP in response to changing wireless condition. We have investigated the fundamental characteristics of the proposed architecture obtained from simulations in [7], and shown that the proposed architecture can attain the excellent throughput performance and improve total throughput and fairness in STA throughput very much.

Then, we here examine the decentralized architecture in terms of incremental deployability and robustness to changing condition of wireless LAN from a practical point of view. Our major concern will be as follows in this context; How easily and smoothly our decentralized architecture can be widely deployed in the existing wireless LANs and how robust it is against significantly dynamic change of LAN configuration due to AP breakdown or simultaneous arrivals of STAs. Therefore, our contribution of this study is the investigation of proposed architecture from a practical point of view. The proposed architecture will be evaluated through simulations and compared with the existing AP selection architecture. The results show that our architecture can be incrementally deployed without hurting the performance of STAs of existing architecture, and is very robust against the changing condition of wireless LAN.

II. AP selection in IEEE 802.11

In the wireless LAN, STAs must associate with an AP in order to communicate with exterior network. Accordingly, STA must first find the AP; the process of finding APs is called scanning. Scanning may be either passive or active. In the passive scanning procedure, the STA records information from all Beacons it receives on each channel. In the active scanning procedure, the STA transmits a Probe Request frame, and AP will respond by sending a Probe Response frame to the scanning STA. At the conclusion of the scan, the STA has accumulated information about the APs in its vicinity. After compiling these scan results, a STA can select one of the APs, and establish the association with the selected AP. However, the AP selection is an implementation-specific decision, and most vendors currently implement it as follows:

- The STA stores the received signal strength indicator (RSSI) of Beacon or Probe Response Frames. After finishing the scanning procedure, the STA selects the AP with the maximum RSSI.
- The STA continuously monitors the quality of the RSSI from other APs after establishing the association with

0-7803-8521-7/04/$20.00 © 2004 IEEE

selected AP. When the STA recognizes that one of other APs would be a better choice, it initiates the re-association procedure. The information used to make that decision are also implementation matter.

This AP selection strategy using RSSI leads to the concentration of many STAs in a few APs. This overload of the AP will lead to both performance and fairness degradation and STAs cannot use the resource of wireless LAN effectively. Therefore, in [7], we have proposed the decentralized AP selection architecture and clearly shown that fundamental characteristics of proposed architecture are suitable very much. Thus, our attention should be paid to the practicability of proposed architecture, and therefore, we examine it in this study.

III. Mechanisms for Decentralized AP Selection

In this section, the mechanism for decentralized AP selection will be described, which is first introduced in [7]. The fundamental algorithm and the dynamic AP selection mechanism will be treated. The former provides the new basis for STAs in order to select an effective AP. The latter allows each STA to dynamically change its accessing AP in response to changing wireless condition.

In the proposed algorithm, each STA first estimates its achievable throughput for each AP, and then selects the AP being expected to provide the maximum throughput. Namely, each of STAs tries to optimize its own throughput locally. This algorithm is referred to in short as the algorithm for MLT (Maximizing Local Throughput). From [1], transmission time t_T in order to transmit a packet of Data [bits] is given by:

$$t_T = RTS + CTS + \frac{Data(bits)}{Rate(b/s)} + ACK + DIFS + 3SIFS \tag{1}$$

We here define P as the PER (Packet Error Rate) in order to take into account of the wireless link condition between STA and AP. In this case, average transmission time T_w which is required for sending and receiving a packet correctly is given by:

$$T_w = t_T + \sum_{i=1}^{\infty} P^i \cdot (1-P) \cdot i \cdot t_T = \frac{t_T}{1-P} \tag{2}$$

If we assume the ideal case in which the probability of collision can be negligible, N STAs that communicate with an AP can evenly share the wireless access resources, so that throughput θ will be given by the following equation:

$$\theta = \frac{Data}{T_w} = \frac{Data \cdot (1-P)}{t_T \cdot N} \tag{3}$$

Equation (3) simply depends on the following function for each AP when packets are of same size:

$$W_{MLT} = \frac{1-P}{N} \tag{4}$$

where P denotes the PER, which can be obtained from the received signal strength, and N denotes the number of STAs which are currently accommodated by the AP. In order to provide each STA with the additional information on N, APs should be slightly modified to add the information on the Probe Response and Beacon frames. Each STA can obtain the number of STAs accommodated by each AP, N, through scanning process. We may also be able to use the 802.1X in order to provide the related information. Finally, the AP with the largest W_{MLT} will be selected.

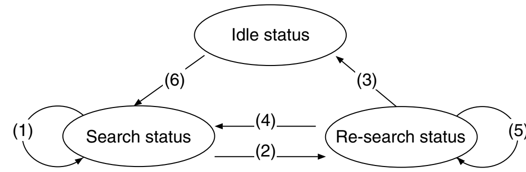

Fig. 1. The Dynamic AP Selection

Since the wireless link condition can change, we have proposed a new dynamic selection mechanism in order to cope with the change in the condition of wireless LAN. Our dynamic AP selection mechanism has three states: search state, re-search state, and idle state. Fig. 1 illustrates the relationship among these states, and the dynamic selection mechanism is precisely described as follows; each of the figures in Fig. 1 corresponds to the number of the following items.

(1) A STA has selected some AP as an appropriate one. The STA calculates the weighted function according to the algorithm at the interval of SI.
(2) If some new AP, denoted by AP_{new}, is selected as an appropriate one as a result of calculation of weighted function, the STA transits to re-search state and re-calculates the weighted function after *Backoff Time* that is determined by random variable in $[0,\ 1]$.
(3) If the AP_{new} is selected as an appropriate AP again after re-calculation, the STA actually roams to the AP_{new}, and transits to idle state.
(4) If the current AP is selected after re-calculation, the STA returns to the search state.
(5) If some other AP is selected, which is different from both the current one and the AP_{new}, the STA remains the re-search state. The newly selected AP is regarded as AP_{new}, and the STA re-calculates the weighted function after *Backoff Time*.
(6) After roaming to the new AP, the STA waits for the Idle Time (IT) in order to prevent the ping-pong effect, and returns to the search state.

IV. Simulation Model

In our simulation model, a source (fixed host) communicates with 40 STAs via four APs. Each AP operates at a data rate of 11 Mb/s on different RF channels to prevent the interference among the APs, and is located as shown in Fig. 2. In addition, we use the shadowing model over the wireless link. Simulation experiments were performed by using the network simulator ns [8] after modifying it to the 802.11b.

Sender $Source$ sends TCP packets to 40 STAs via $Router$ and four APs. The TCP variant employed here is TCP with SACK option [9], and its segment is of 1,500 bytes. It is assumed that each TCP flow is used for greedy file transfer. The wired link between $Source$ and $Router$ is 100 Mb/s in bandwidth and 10 μsec in propagation delay, similarly the wired link between $Router$ and each AP is 100 Mb/s in bandwidth and 1 μsec in propagation delay.

Furthermore, as mentioned previously, many STAs can join some specific AP and traffic load imbalance will thus happen among APs in reality. In order to take into account of this feature, STAs are located uniformly in a rectangular area of 30m by 30m, which provides most biased situation in terms of STAs' geographical location. Arrivals of STAs are uniformly distributed over a period of 10 seconds. After all of 40 STAs are located within the wireless LAN, they will stay there during simulations. As for AP selection algorithm, we use

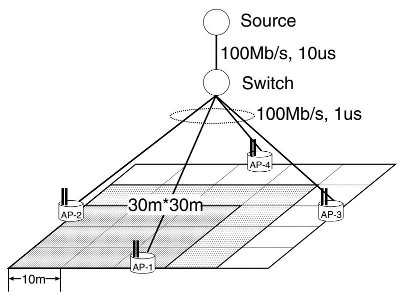

Fig. 2. Arrangement of APs

the following algorithm: (i) MLT, (ii) RSS (Received Signal Strength), which is currently used in existing wireless LAN. In MLT, each of STAs checks whether its current AP is still the best or not and will roam to new AP according to the dynamic AP selection mechanism if necessary.

To quantify our proposing algorithm, we employ the total throughput, maximum and minimum throughput of all STAs, and the distribution of the average throughput as performance measure. In addition, we also use the balance index β introduced in [10] to reflect some fairness. Suppose B_i is the average throughput of STA i, then we define the balance index β to be:

$$\beta = \frac{(\sum B_i)^2}{(n \cdot \sum B_i^2)} \tag{5}$$

where n is the total number of STAs allocated in the simulation. The balance index has the property that it takes 1 when all STAs have exactly the same throughput and it gets closer to $1/n$ when throughput of STAs are heavily imbalanced.

V. Simulation Results

We now present the simulation results. As mentioned above, our major concern is the incremental deployability and robustness from a practical point of view. Regarding the former, we examine whether or not the proposed architecture can share the wireless LAN resource with the existing scheme without harming that. Regarding the latter, we examine whether or not the proposed architecture can adapt itself to the changing condition of wireless LAN, e.g., when AP-1 or AP-2 has a breakdown, or some STAs arrive at an AP simultaneously.

A. Deployability

Simulation experiments have been carried out for 250 seconds, and part of them, i.e., of 180 seconds from 70 to 250 seconds, is actually used to calculate the throughput in order to prevent the effect of the transient state of the TCP behavior.

In order to consider the deployability, we here examine a case where the wireless resource is shared by both STAs with MLT and STAs with RSS. Therefore, some STAs select their APs by the MLT and remaining STAs by the RSS. Figs. 3 and 4 illustrate the throughput characteristics of RSS and MLT as a function of ratio of the number of STAs with MLT to the number of total STAs respectively. Furthermore, Tab. I shows the throughput characteristics for some ratios of the number of STAs with MLT. If the percentage of STAs with MLT is 20 %, 8 STAs select their accessing APs with MLT algorithm, and remaining 32 STAs with RSS algorithm.

As can be seen in Fig. 3 and 4, the maximum throughput of each algorithm significantly decreases with the increase of ratio of STAs with MLT. As the number of STAs with MLT increases, they can be distributed over all APs due to the MLT algorithm, so the monopolization of AP by few STAs happens less frequently. On this account, the average throughput of RSS decreases to 317.902 Kb/s from 369.503 Kb/s with the increase of the ratio up to 30 %.

On the other hand, the minimum throughput of RSS is not harmed, but improved with the increase of the ratio of MLT STAs, as shown in Fig. 3 and Tab. I. Because of the MLT algorithm, the STAs are widely and evenly distributed over all APs, as mentioned previously. Accordingly, the wireless resource is more fairly used by STAs with the increase of the number of STAs with MLT and the minimum throughput of

TABLE I
Throughput for some ratio of STAs with MLT

[%]	maximum [Kb/s] RSS	maximum [Kb/s] MLT	average [Kb/s] RSS	average [Kb/s] MLT	minimum [Kb/s] RSS	minimum [Kb/s] MLT
0	3483.24	-	369.503	-	161.2	-
30	847.447	914.893	317.902	461.356	202.813	251.227
50	581.853	722.693	329.960	406.271	252.560	253.627
70	526.493	651.633	323.525	383.321	259.613	250.087
100	-	563.373	-	386.473	-	275.867

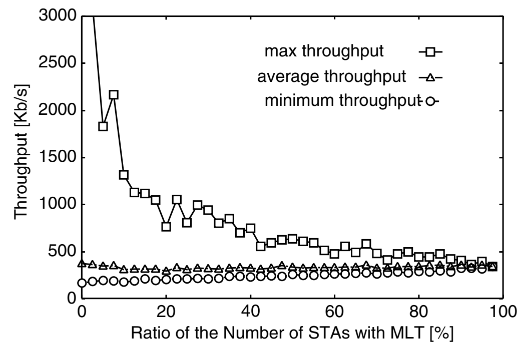

Fig. 3. Throughput Performance of RSS

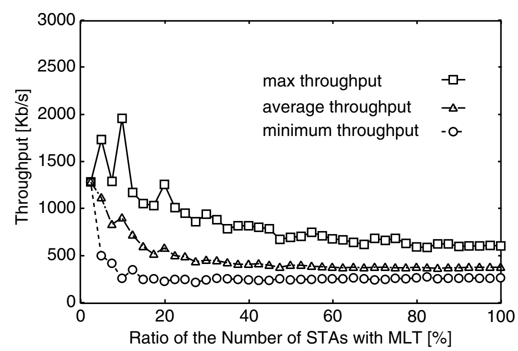

Fig. 4. Throughput Performance of MLT

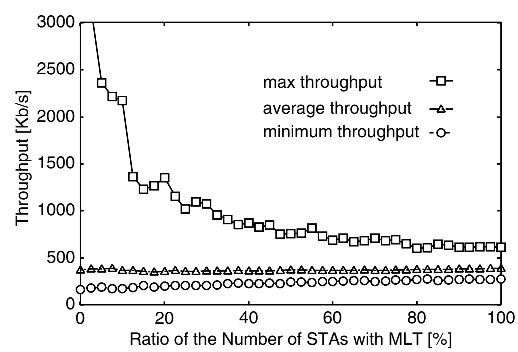

Fig. 5. Total Throughput Performance

RSS is improved as a result.

The average throughput of MLT is always higher than that of RSS, as shown in Tab. I. It is noted that this can be achieved by preventing monopolization of AP by a few STAs, and does not hurt the minimum throughput performance of STAs with RSS. Furthermore, STAs with MLT can achieve high throughput on average, in particular, when a ratio of the number of STAs with MLT is under 20 %, as shown in Fig. 4. This advantage is significant benefit to the STAs with MLT. These features will enable the proposed architecture to be deployed smoothly.

Finally, Fig. 5 shows the total throughput of STAs with RSS and MLT. As shown in this figure, our proposing architecture does not harm but improve the minimum and average throughput in a case where it is used together with the existing architecture, while adversely decreasing the maximum throughput performance because it avoids the monopolization of APs, as mentioned above. Consequently, we can say that the proposed architecture can share the wireless LAN resource with the existing architecture without harming that from a practical point of view. Furthermore, the proposed architecture can improve the minimum throughput of both types of STAs, and can thus achieve fairness in their throughput performance very well.

B. Robustness

Next, we examine the robustness of our decentralized architecture against changing condition of wireless LAN from a practical point of view. We here deal with two cases as the changing condition: the AP breakdown and the simultaneous arrivals of STAs. In both of the cases, the robustness of proposed architecture is compared with the existing RSS.

1) AP Breakdown: First, we examine the AP breakdown. Simulation experiments have been carried out for 490 seconds, and an AP-1 or AP-2 is randomly breakdown in each trial at the 250 seconds. The part of them, i.e., of 180 seconds both from 70 to 250 seconds and from 310 to 490, is actually used to calculate the throughput and compare the performance before and after the AP breakdown in order to prevent the effect of the transient state of the TCP behavior.

The throughput characteristics obtained by simulations are shown in Tab. II. As shown in Tab. II, any of the throughput characteristics given there decreases because the transmission capacity decreases due to the AP breakdown. However, the minimum throughput of MLT is approximately twice as much as that of RSS. On the other hand, the average throughput of RSS is larger than that of MLT after the AP breakdown. In order to investigate the reason, we examine the distribution of average throughput in each algorithm. Figs. 6 and 7 illustrate the distribution of average throughput of 40 STAs in RSS and MLT, respectively. Since AP-1 or AP-2 has a breakdown, the average throughput is degraded in each of the figures. However, in RSS, 0.4 % of STAs attains the throughput over 1 Mb/s regardless of AP breakdown, as shown in Fig. 6. This is because only quite a few STAs happen to be located near by some specific AP. On this account, the average throughput of RSS is larger than that of MLT after the AP breakdown. This can cause unfairness in terms of achievable throughput of the STAs. As for MLT, the average throughput of STAs is distributed over a narrower range, as shown in Fig. 7, in comparison with that of RSS algorithm, which spreads over a wide range from quite low throughput to high one in Fig. 6. Accordingly, our proposing algorithm can achieve a high fairness in STA throughput even when an AP has a breakdown.

TABLE II
THROUGHPUT BEFORE AND AFTER AP BREAKDOWN

Algorithm		Throughput Max [Kb/s]	Avg. [Kb/s]	Min. [Kb/s]
RSS	Before	3591.01	369.954	161.740
	After	2409.95	239.921	68.753
MLT	Before	581.247	377.958	278.047
	After	391.053	234.932	135.853

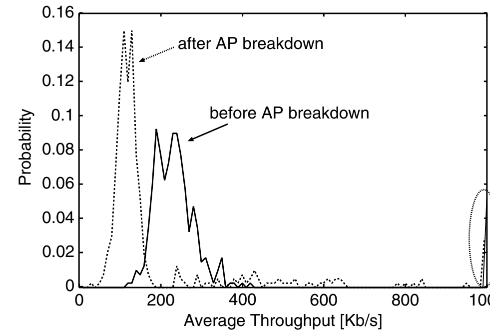

Fig. 6. Distribution of Average Throughput in RSS

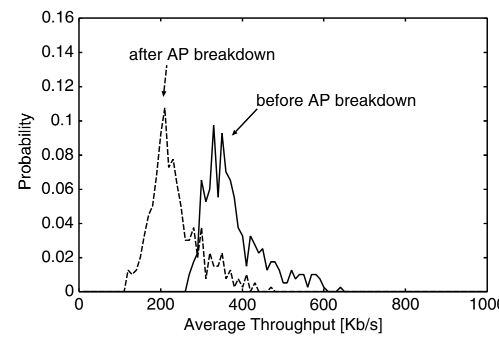

Fig. 7. Distribution of Average Throughput in MLT

TABLE III
BALANCE INDEX

	MSS	RSS
Before breakdown	0.968	0.278
After breakdown	0.939	0.348

Next, we examine the balance index in order to clarify the fairness in STA throughput. Table III shows the balance index before and after AP breakdown. In RSS, each STA selects its AP with the maximum RSSI after AP breakdown, so a few STAs connected with the breakdown AP are very likely to select the AP which is monopolized by only a few STAs. Consequently, the maximum throughput decreases and the difference between the maximum and minimum throughput shrinks, as shown in Tab. II. As a result, the balance index of RSS increases to 0.348 from 0.278, as shown in Tab. III. On the contrary, the balance index of MLT is still as much as 0.9 regardless of AP breakdown, whereas the balance index of RSS is less than approximately 0.4. Namely, we see that the proposed architecture can achieve high fairness in STA throughput even when the AP has a breakdown.

2) Simultaneous arrivals of STAs: Finally, we examine the simultaneous arrivals of STAs. We here deals with a case where 10 STAs arrive at AP-1 simultaneously at the 250 seconds. Other conditions are the same as ones in the previous section.

TABLE IV
THROUGHPUT AFTER 10 STAS ARRIVING AT A SAME TIME

Algorithm		Throughput		
		Max [Kb/s]	Avg. [Kb/s]	Min [Kb/s]
RSS	Before	3493.32	379.273	151.153
	After	3491.63	303.073	107.647
MLT	Before	614.833	379.133	273.12
	After	536.78	297.229	199.827

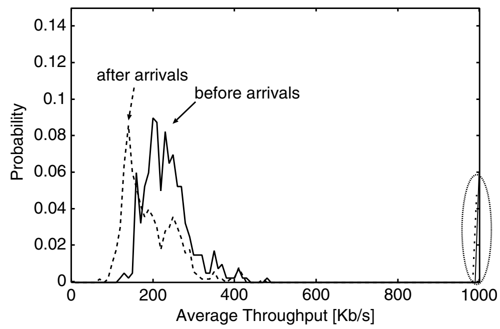

Fig. 8. Distribution of Average Throughput in RSS

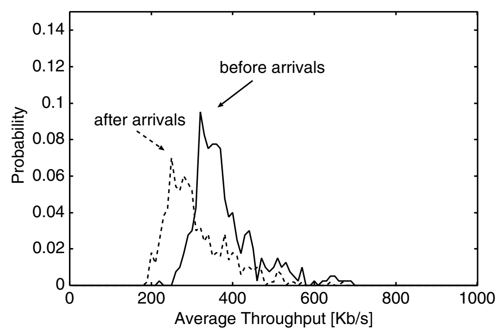

Fig. 9. Distribution of Average Throughput in MLT

The throughput characteristics obtained by simulations are shown in Tab. IV, and the distribution of average throughput in each algorithm is shown in Fig. 8 and 9. As shown in Tab. IV, the minimum throughput of MLT is larger than that of RSS by approximately 100 Kb/s. However, the average throughput of RSS is larger than that of MLT after the simultaneous arrivals of STAs, as in the case of AP breakdown. From Fig. 8, in RSS, 0.4 % of STAs attains the throughput over 1 Mb/s regardless of simultaneous arrivals of STAs; i.e., only a few STAs monopolize the transmission capacity of some APs. Therefore, the average throughput of RSS is larger than that of MLT after the arrivals of STAs.

Furthermore, in RSS, additional STAs connect with the AP-1 due to the RSS algorithm and STAs already connected with AP-1 do not roam another AP in response to arrivals of STAs. The maximum throughput of RSS is thus still as much as approximately 3.5 Mb/s after the arrivals of STAs, as shown in Tab. IV. On the other hand, the minimum throughput decreases. Therefore, as shown in Tab. V, the balance index decrease to 0.244 from 0.296 after the arrivals of STAs, which is different from that of AP breakdown.

On the contrary, the balance index of MLT is still as much as 0.9 regardless of arrivals of STAs. Consequently, the proposed architecture can attain the high fairness in STA throughput regardless of simultaneous arrivals of STAs. From these results, we can say that the proposed architecture can achieve high robustness and fairness in STA throughput compared with the existing architecture from a practical point of view.

TABLE V
BALANCE INDEX AFTER 10 STAS ARRIVING AT THE AP-

	MLT	RSS
Before Arrivals	0.960	0.296
After Arrivals	0.941	0.244

VI. CONCLUSION

Wireless LANs have been widely deployed, and multiple APs will be much more likely to be available there for STAs. Therefore, how to select an appropriate AP among available APs is very important matter. So far, we have proposed the decentralized AP selection architecture, and clearly shown the fundamental characteristics of it. In this paper, we have examined the incremental deployability and robustness. Our contribution of this study is the investigation of proposed architecture from a practical point of view. Regarding the incremental deployability, we have examined whether or not MLT can share the wireless LAN resource with the existing scheme without harming that. From the simulation result, we have shown that MLT can improve the minimum throughput of both types of STAs, and can thus achieve fairness in their throughput performance very well. Regarding the robustness, we have examined whether or not MLT can adapt itself to the changing condition of wireless LAN. Two different cases have been treated: the AP breakdown and the simultaneous arrivals of STAs. In both of the cases, we have shown that proposed algorithm is very robust against the changing condition and can achieve a high fairness in STA throughput in comparison with the RSS even when the condition of wireless LAN changes. Therefore, we can say that proposed AP selection mechanism can be incrementally deployed without hurting the performance of STAs of existing architecture and achieve a high robustness from a practical point of view.

ACKNOWLEDGEMENT

This work was supported in part by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (A) (15200005) and in part by National Institute of Information and Communications Technology under the JGN2 R&D Project.

REFERENCES

[1] IEEE, "Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *IEEE Standard 802.11*, September 1999.
[2] B. P. Crow, I. Widjaja, J. G. Kim, and P. T. Sakai, "IEEE 802.11 Wireless Local Area Networks," *IEEE Communications Magazine*, Vol. 35, No. 9, pp. 116–126, September 1997.
[3] A. Balachandran, G. M. Voelker, P. Bahl, and V. Rangan, "Characterizing User Behavior and Network Performance in a Public Wireless LAN," *In the Proceedings of ACM SIGMETRICS'02, Marina Del Rey*, June, 2002.
[4] D. Tang and M. Baker, "Analysis of a Metropolitan-Area Wireless Network," *In the Proceedins of ACM Mobicom 1999*, pp. 12–23, August, 1999.
[5] D. Tang and M. Baker, "Analysis of a Loca-Area Wireless Network," *In the Proceedins of ACM Mobicom 2000*, pp. 1–20, August, 2000.
[6] D. Kotz and K. Essien, "Analysis of a Campus-wide Wireless Network," *In Proceedings of the Eighth Annual International Conference on Mobile Computing and Networking*, pp. 107–118, September, 2002
[7] Y. Fukuda, T. Abe, and Y. OIE, "Decentralized Access Point for Wireless LANs," *In the Proceedings of WTS 2004*, SA3, May 2004.
[8] The VINT Project, Nework Simulator NS, *http://www.isi.edu/nsnam/ns/*.
[9] M. Mathis, J. Mahdavi, S. Floyd, and A. Romanow, "TCP Selective Acknowledgment Options," RFC2018, October 1996.
[10] Dah-Ming Chiu and Raj Jain, "Analysis of the Increase and Decrease Algorithms for Congestion Avoidance in Computer Networks," *Computer Networks and ISDN Systems, vol. 17*, pp. 1–14, 1989.