A Strategy for Differentiated Access Service Selection Based on Application in WLANs*

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***ABSTRACT*—The service quality of a station in IEEE 802.11 wLAN (wireless Local Area Networks) is strongly influenced by which access point it associates with. Therefore, a key challenge is how to select an appropriate access point from multiple available ones. Conventional association protocols have been proved to be not effective. In this paper a strategy for differentiated access service selection based on users' running application is presented. The goals of the proposed strategy are: to select and dynamically reselect access point based on user's actual QoS requirements on bandwidth and delay leading to differentiated service quality provision; and to redistribute network load across access points. The effectiveness of our strategy is evaluated through simulation study, confirming better performance compared with conventional ways.**

***Keywords—802.11* wLAN; AP selection; differentiated; AHP; load balancing; QoS requirement of network application**

I. INTRODUCTION

IEEE 802.11 wLAN has been a popular connectivity method, which is widely deployed in hotels, airports, cafes, etc, as its ease of deployment, low cost and flexibility. The wLAN environment consists of Access Points (APs) and Stations (STAs), and each STA associates with an available AP in order to access to the network. With the fast-growing of wLANs, multiple APs could be available for STAs. Thus, selecting a suitable AP for each STA to obtain satisfactory service is very important. The current AP selection policy is based on the RSSI (Received Signal Strength Indication). A STA always associates with an AP from which it has received the strongest RSSI. Afterwards, it stays associated until the STA is powered down or the AP shuts down its service. However this simple strategy might lead to bad performance and load imbalance[14], since users' location distribution is usually quite unevenly around APs[10].

Recently, several AP selection policies have been proposed, which can be classified as centralized or distributive. Centralized approach as proposed in [1] usually needs a designated server to collect and analyze the network information, then to decide and distribute associate permissions through the network, but it needs additional hardware and it is not compatible with current vendors. While in distributive approach[8, 15], each STA selects AP independently based on its own interests. It is more popular because of its low cost and eases of deployment.

Previous researches focus on proposing selection metrics to measure potential performances of users' association decisions, mainly through optimizing single criterion. Works by[7, 13] propose selection metrics through maximizing achievable throughput of a STA for each AP. Work by[6] designs a schema for selecting the best AP by bandwidth estimation. Work by [2] measures the traffic loads as the selection criterion by estimating frame delay. However, it is observed that most of today's popular Internet applications have their specific QoS requirements. Some applications require light bandwidth. Some applications require a relatively high bandwidth. To real time applications short delay is suggested. While to some applications both short delay and high bandwidth are required. Thus, these previous studies for optimizing one criterion such as throughput, and considering all users as the same by adopting same selection metric for each STA cannot always satisfy QoS requirements of every user. Work by [1] specifies the bandwidth requirement bounds for users. Each STA selects the AP which can provide its minimum bandwidth. In [12], each STA selects an AP through estimating the ratio of required bandwidth to available bandwidth. These studies take into consideration different requirements of each user, however no concerns about other than bandwidth requirements.

The motivation of the paper is to design a strategy for providing differentiated access service selection to users based on their current application's QoS requirements. According to applications' different QoS requirement on bandwidth and delay, users are classified into four types. For users of each type, the selection metric is generated by using the AHP (Analytic Hierarchy Process), which is a multi-criteria decision-making method. A static access service selection algorithm based on the corresponding selection metric is proposed, using estimated available throughput and transmission delay. In addition, a dynamic selection algorithm consisting of Periodic and Aperiodic dynamic selection is presented to enhance static selection.

The rest of this paper is organized as follows: Section Ⅱ analyzes applications' QoS requirements and defines four types of applications. Section Ⅲ provides explanation of the differentiated selection metrics and proposes the static AP

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access service selection algorithm. Section Ⅳ describes the dynamic AP selection algorithms. Then, Section Ⅴ shows the performance analysis of the strategy via simulation. Finally, Section Ⅵ concludes this paper.

II. Classification Of Applications

Different applications have different QoS requirements. Based on their either high or low requirements on bandwidth and delay [3], network applications can be classified into four types: (1)Type1: applications require a relatively high bandwidth and have not much demand on delay, like Web Browsing and FTP; (2)Type2: applications require a relatively short delay and have not too much demand on bandwidth, like Audio-graphics Conferencing and VoIP; (3)Type3: applications need relatively high bandwidth and short delay, like Audio Broadcasting, Video Broadcasting, and Video Conferencing; (4)Type4: applications have special requirements neither on bandwidth nor on delay. Like Email, Telnet and Internet Relay Chat.

III. Static Selection Algorithms

Selection metric for users of each type is generated by using AHP. The AHP [11] is a theory of measurement developed by Thomas L.Saaty in the 1970s, which has been widely used in multi-criteria decision-making problems of choice and prioritization. It directs how to determine the priority of a set of alternatives and the relative importance of attributes, and construct the pairwise comparison matrix to judge the weights. It can transform different user's qualitative and semi-quantitative personal preference into quantitative numeric weights for forwarding access service selection. The procedure is as follows:

A. Model the problem as a hierarchy

Fig. 1 shows the hierarchy of the AHP model consisting of the goal, criteria and the alternatives. The goal is to select an AP which is placed on the first level of the hierarchy. Two criteria namely throughput and delay form the second level. Obviously, more elements like packet loss could be added to the second level. The lowest level consists of the alternatives, namely the different APs to be evaluated. Four APs are assumed to be available for STAs in the following.

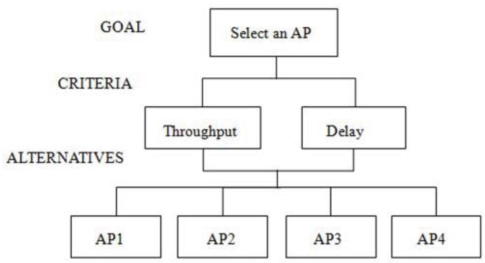

Fig. 1. Hierachy of selecting an AP selection

B. Generate Level 2 Pairwise Comparisons

This step is to establish priorities of criteria for users of each type respectively, by judging throughput and delay in pairs for which one is considered more important under that criterion and how much more. Using the fundamental scale table of [9], judgments are represented by a numerical value using a scale of 1-9 where 1 denotes equal importance and 9 denotes the highest degree of importance.

For Type1 users, the following is matrix of pairwise comparisons of criteria with respect to the overall goal. As THROUGHPUT is considered strongly important (5 times) than DELAY, the value 5 is entered in the (1, 2) position with the reciprocal value 1/5 entered in the (2, 1) position.

$$\begin{pmatrix} 1 & 5 \\ 1/5 & 1 \end{pmatrix} \tag{1}$$

For Type2 users, the following is matrix of pairwise comparisons of criteria with respect to the overall goal. As DELAY is considered strongly important (5 times) than THROUGHPUT, the reciprocal value 1/5 is entered in the (1, 2) position with the value 5 entered in the (2, 1) position.

$$\begin{pmatrix} 1 & 1/5 \\ 5 & 1 \end{pmatrix} \tag{2}$$

For Type3 users, the following is matrix of pairwise comparisons of criteria with respect to the overall goal. As DELAY is considered moderately important (3 times) than THROUGHPUT, the reciprocal value 1/3 is entered in the (1, 2) position with the value 3 entered in the (2, 1) position.

$$\begin{pmatrix} 1 & 1/3 \\ 3 & 1 \end{pmatrix} \tag{3}$$

For Type4 users, the following is matrix of pairwise comparisons of criteria with respect to the overall goal. As THROUGHPUT and DELAY is considered of the same importance, the value 1 is entered in the (1, 2) position with the reciprocal value 1 entered in the (2, 1) position.

$$\begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} \tag{4}$$

Then the scale of priorities is derived. By solving for the principal eigenvector of the matrices and normalizing the results, the followings are vectors of relative weights for Type1, Type2, Type3 and Type4 users respectively:

$$(THROUGHPUT,\ DELAY) = (0.87, 0.13) \tag{5}$$

$$(THROUGHPUT,\ DELAY) = (0.13, 0.87) \tag{6}$$

$$(THROUGHPUT,\ DELAY) = (0.33, 0.67) \tag{7}$$

$$(THROUGHPUT,\ DELAY) = (0.5, 0.5) \tag{8}$$

C. Generate Level 3 Pairwise Comparisons

This step is setting up matrices of paired comparisons for four candidate APs in level 3 compared with respect to criteria in level 2. Ways to measure AP's potential available throughput and transmission delay are presented as follows.

1) Potential Availble Throughput Estimation

From[5], the transmission time T used for transmitting a packet of length $L(bits)$ is given by:

$$T = T_{RTS} + T_{CTS} + DIFS + 3SIFS + \frac{L}{Rate(bits/s)} + T_{ack} \quad (9)$$

Where $DIFS$ is the DCF (Distributed Coordination Function) Inter-Frame Space, $SIFS$ is the Short Inter-Frame Space.

Then, the average transmission time $\overline{T}$ required for sending and receiving a packet correctly can be given by:

$$\overline{T} = T + \sum_{i=1}^{\infty} P^{i} \cdot (1-P) \cdot i \cdot T = \frac{T}{1-P} \quad (10)$$

Where P is defined as PER(Package Error Rate), which can be obtained from the received signal strength.

Assuming the ideal case in which the probability of collision is negligible, N STAs that associate with an AP can evenly share the resources. So the potential throughput of a STA associating with an AP k can be given by:

$$tp_K = \frac{L}{\overline{T} \cdot N} = \frac{L \cdot (1-P)}{T \cdot N} \quad (11)$$

where N denotes the number of the number of STAs which currently communicate with the AP k. APs should be modified to add the information of N on the Probe Response and Beacon frames. Thus tp_1, tp_2, tp_3 and tp_4 are calculated to denote potential throughput for each candidate AP.

2) Transimission Delay Estimation

In active scanning STAs firstly transmits the Probe Request frames to identify APs in the area, soliciting Probe Response frames from APs. The transmission delay de_k is calculated by recording the time from the STA sends out the Probe Request until the time it receives the Probe Response from AP k. STAs should be modified to record the transmission delay. Thus de_1, de_2, de_3 and de_4 are calculated to denote transmission delay for each AP.

Then by comparing each AP's tp_K in pairs according to criterion THROUGHPUT, and comparing each AP's de_k in pairs according to criterion DELAY, the following matrices of paired comparisons are generated. Here, the relative importance of tp_i and tp_j is judged by tp_i / tp_j, the relative importance of $1/de_i$ and $1/de_j$ is judged by de_j / de_i.

$$\begin{pmatrix} 1 & tp_1/tp_2 & tp_1/tp_3 & tp_1/tp_4 \\ tp_2/tp_1 & 1 & tp_2/tp_3 & tp_2/tp_4 \\ tp_3/tp_1 & tp_3/tp_2 & 1 & tp_3/tp_4 \\ tp_4/tp_1 & tp_4/tp_2 & tp_4/tp_3 & 1 \end{pmatrix} \quad (12)$$

$$\begin{pmatrix} 1 & de_2/de_1 & de_3/de_1 & de_4/de_1 \\ de_1/de_2 & 1 & de_3/de_2 & de_4/de_2 \\ de_1/de_3 & de_2/de_3 & 1 & de_4/de_3 \\ de_1/de_4 & de_2/de_4 & de_3/de_4 & 1 \end{pmatrix} \quad (13)$$

Next again by solving for the principal eigenvector of the matrix and then normalizing the result, the follows are the local derived scales for criterion THROUGHPUT and DELAY respectively:

$$(\text{AP}1, \text{AP}2, \text{AP}3, \text{AP}4) = (t_1, t_2, t_3, t_4) \quad (14)$$

$$(\text{AP}1, \text{AP}2, \text{AP}3, \text{AP}4) = (d_1, d_2, d_3, d_4) \quad (15)$$

D. Derive overall priority

The last step is to synthesize the overall priority scale by multiplying as follows, where the corresponding $(THROUGHPUT, DELAY)^T$ for users of each type is subjective which is displayed in (5)-(8). Thus, $Prio_i$ is the overall priority of AP_i. Whenever a STA selects an AP, the most preferred AP is the AP with the highest $Prio$.

$$\begin{pmatrix} t_1 & d_1 \\ t_2 & d_2 \\ t_3 & d_3 \\ t_4 & d_4 \end{pmatrix} \begin{pmatrix} THROUGHPUT \\ DELAY \end{pmatrix} = \begin{pmatrix} Prio_1 \\ Prio_2 \\ Prio_3 \\ Prio_4 \end{pmatrix} \quad (16)$$

IV. Dynamic AP Selection Algorithms

Since the network state can change and STA's running application would change, the AP firstly selected according to the static selection algorithm may be no longer the best one, the dynamic AP selection algorithms consisting of periodic and aperiodic selection algorithm are proposed.

A. Periodic Dynamic Selection

A STA needs to reevaluate the function $Prio_i$ after some time period T_{per} and re-associate with a new AP if it has higher $Prio$. The time period T_{per} is dynamically adjusted in order to reduce unnecessary re-association. The Periodic Dynamic Selection algorithm is summarized as follows:

Step1: Broadcast Probe Request Frames.

Step2: Calculate $Prio$ of each AP; select the AP with the highest $Prio$.

Step3: Communicate for time period T_{per}.

Step4: Broadcast Probe Request Frames.

Step5: Calculate $Prio$ of each candidate AP. If found AP_{new} with higher $Prio$, then {associate with AP_{new}; set $T_{per} = T_{per}/2$}. Else {set $T_{per} = T_{per} \cdot 2$}. Go to Step 3.

B. Aperiodic Dynamic Selection

As the strategy is based on user's application, once user changes application, selection metric may changed. So the STA should reevaluate whether the current AP is still the best depending on new selection metric. In Periodic Dynamic Selection, the STA can reselect till the next period time T_{per}. It may be not in time if the T_{per} is too long; while shortening T_{per} will cause frequently periodic reselection. Thus the Aperiodic Dynamic Selection is proposed to make STA can actively react to its application changes timely. The algorithm is described as follows:

Step1: Broadcast Probe Request Frames.

Step2: Calculate $Prio$ of each AP; select the AP with the highest $Prio$.

Step3: Set $Type_{old} = Type_{current}$. Communicate for time period T_{aper} .

Step4: If $Type_{current}$ equals $Type_{old}$ then {go to Step 3}. Else {broadcast Probe Request Frames.}

Step5: Calculate $Prio$ of each AP. If found AP_{new} with higher $Prio$, then {associate with AP_{new} }. Go to Step 3.

V. PERFORMANCE ANALYSES

In this section, the performance of the proposed strategy is evaluated via simulations on the Network Simulator 2 (NS2). The location of 4 APs is demonstrated in *Fig. 2*. Each AP is assigned to a fixed 802.11b channel. The radio coverage of each AP is an identical circle with a radius of 250 meters. The channel access in IEEE 802.11 MAC layer is implemented using DCF and using RTS/CTS mechanism. The physical layer is based on 802.11b with 11 Mbps. RSSI is calculated according to the received signal power. Each AP is connected to a fixed Server with wired link of 5Mb/s in bandwidth and 2ms in propagation delay.

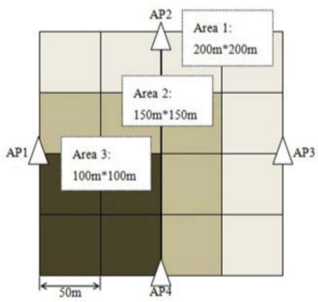

Fig. 2. Three location areas of APs and STAs

The location area is illustrated in *Fig. 2*. As many STAs can join some specific AP in reality, 3 location areas are introduced. All STAs are uniformly located in a rectangular area of 200m by 200m, 150m by 150m, and 100m by 100m, which called Area1, Area2 and Area3 respectively. In Area1, STAs are most uniformly distributed to each of APs, while they are concentrated within a most limited area in Area3.

Four types of users are modeled in the simulation, and each type has different application profile reflecting the traffic mix generated by users of that type: (1) Type1 users: Generate high heavy workloads. The traffic is characterized by ftp application over TCP using NS2 default parameter settings; (2) Type2 users: Generate light workloads, requiring low delay. The traffic is characterized by CBR over UDP of 60KB page size and 0.5min interval arrival time; (3) Type3 users: Generate heavy workloads, requiring low delay. The traffic is modeled by an on/off source with exponentially distributed on and off periods of 350ms and 650ms respectively. Packet size is of 1000 KB page size. Rate of traffic generated during the on periods is 60kbps; (4) Type4 users: Generate light workloads, having no requirements on delay. The traffic is characterized by telnet application over TCP using NS2 default parameter settings.

A. Experiement1

Experiment1 is to evaluate the effect of static selection algorithm on guaranteeing differentiated service quality. 30 stations are located uniformly randomly in Area3, including 10 Type1, 5 Type2, 10 Type3 and 5 Type4 users, reflecting an unevenly distributed scenario. All STAs communicate with the fixed Server via 4 APs. They start the active scanning one by one and start their traffic generation at 100s.

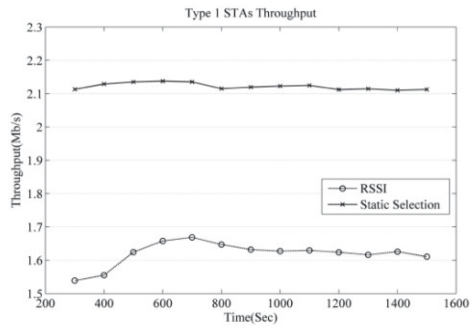

Fig. 3. Type 1 STAs throughput vs. time

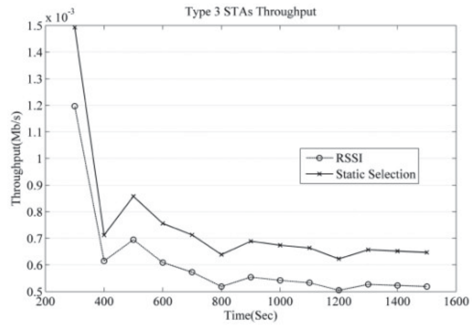

Fig. 4. Type 3 STAs throughput vs. time

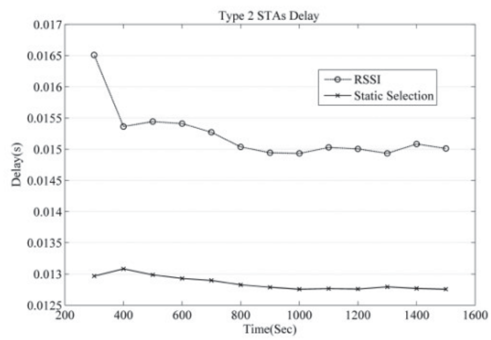

Fig. 5. Type 2 STAs delay vs. time

Fig. 3 and *Fig. 4* show that, the average throughput of Type1 and Type3 users gain by 31.0%, 23.5% respectively with static selection algorithm. *Fig. 5* and *Fig. 6* show that the average delay of Type2 and Type3 users decrease for 15.6%, 35.0% respectively. This is because Type1 and Type3 users require relatively high bandwidth, their selection metrics prefer AP from which they can obtain higher throughput. Type2 and Type3 users require relatively short delay, their selection metrics prefer APs from which can obtain shorter delay. It confirms superority of the Static Selection on satisfying differentiated access service requirements of users in different type.

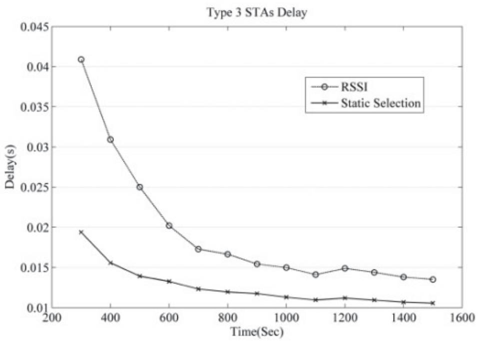

Fig. 6. Type 3 STAs delay vs. time

B. Experiement2

Experiment2 is to verify the performance of dynamic selection algorithms. There are 20 users in all and 5 users of each type respectively, communicating with the Server via 4 APs. The distribution location is as same as the Experiement1. The periodic selection interval is set to 120s. Three scenarios are discussed.

In scene 1, a Type4 user joins in network at 180s, and starts to send messages at 200s, switching its running application to Type1 at 250s. Type1 users require relatively high bandwidth. *TABLE I* shows the STA's average throughput highly increases in 250-300s with Aperiodic Dynamic Selection, because the STA reevaluates APs using Type1 selection metric after STA's application changed at 250s. Average throughput highly increases in 300-350s with Periodic Dynamic Selection algorithms, because the STA will reevaluate APs when periodic reselection interval arrives at 300s. Combining Periodic with Aperiodic Dynamic Selection achieves highest average throughput both in the two periods. It is because the STA will reselection twice; and as other STAs can reevaluate association through their periodic selection, the load redistribution also leads to better performance of the STA.

TABLE I. AVERAGE THROUGHPUT CHANGES

Algorithm	STA's Average Throughput(Mb/s)		
	0s-250s	*250s-300s*	*300s-350s*
RSSI	0.000053	1.787143	1.766364
Aperiodic Dynamic Selection	0.000053	2.161376	2.026890
Periodic Dynamic Selection	0.000053	2.158068	2.160601
Dynamic Selection	0.000053	2.170116	2.161284

In scene 2, the STA switch its application from Type4 to Type2 at 250s. Type2 users require relatively short delay. *TABLE II* depicts, the average delay highly decreases in 250-300s with Aperiodic Dynamic Selection, as the STA reevaluates APs using Type2 selection metric after user changed application at 250s. With Periodic Dynamic Selection, the average delay highly decreases in 300-350s, as the STA reevaluates APs when the periodic selection interval arrives at 300s. Combining Periodic with Aperiodic Dynamic Selection, the average delay is both the lowest in the two periods, as the same reasons discussed in scene 1.

TABLE II. AVERAGE DELAY CHANGES

Algorithm	STA's Average Delay(s)		
	0s-250s	*250s-300s*	*300s-350s*
RSSI	0.005795	0.009134	0.009108
Aperiodic Dynamic Selection	0.005839	0.008432	0.008762
Periodic Dynamic Selection	0.005867	0.008520	0.008717
Dynamic Selection	0.005867	0.008087	0.008430

In scene 3, the STA switch its application from Type4 to Type3 at 250s. Type3 users require relatively high bandwidth and short delay. Since Type3 users generate package not frequently with an interval longer than periodic selection interval, in order to verify performance of each algorithm, the periodic selection interval is set to 420s for Type3 users. *TABLE III* and *TABLE IV* shows, with Aperiodic Dynamic Selection the average throughput highly increases and the average delay highly decreases in 250-600s. That is because the STA reevaluates APs using Type3 selection metric after user changed application at 250s. With Periodic Dynamic Selection the average throughput highly increases and the average delay highly decreases in 600-1000s, as the STA reevaluates APs when the periodic reselection interval arrives at 600s. Combining Periodic with Aperiodic Dynamic Selection still achieves the best.

TABLE III. AVERAGE THROUGHPUT CHANGES

Algorithm	STA's Average Throughput(Kb/s)		
	0s-250s	*250s-600s*	*600s-1000s*
RSSI	8.582055	0.121289	0.073161
Aperiodic Dynamic Selection	10.302733	0.121367	0.075890
Periodic Dynamic Selection	9.842150	0.118892	0.075573
Dynamic Selection	9.842150	0.121481	0.075941

TABLE IV. AVERAGE DELAY CHANGES

Algorithm	STA's Average Delay(s)		
	0s-250s	*250s-600s*	*600s-1000s*
RSSI	0.005796	0.007487	0.007721
Aperiodic Dynamic Selection	0.005827	0.007306	0.006990
Periodic Dynamic Selection	0.005931	0.007155	0.006612
Dynamic Selection	0.005931	0.006355	0.006206

Experiment2's results show, combining Aperiodic with Periodic Dynamic Selection outperforms other algorithms. It can react to user's application changes actively and timely, and adjust the association results through periodic reevaluations, thus providing better performance to users.

C. Experiment3

This experiment is to investigate the effect of the proposed strategy on network overall performance of throughput and load balancing. There are 40 STAs consisting of 10 users in each type, communicating with the Server via 4 APs. They start the active scanning one by one and start traffic generation after all association finished.

(1) Throughput

TABLE V shows minimum, maximum and average throughput of both Static Selection and Periodic Dynamic Selection Algorithms compared to the RSSI algorithm for the three different STAs location areas. The results show, the Min., Max., and Avg. throughput are all increased with Periodic Dynamic Selection. It proves that the proposed strategy can highly improve the network overall throughput.

TABLE V. MIN.,MAX.,AVG. OVERALL THROUGHPUT

Location	Algorithm	Min., Max., Avg. Throughput(Mb/s)		
		Min.	**Max.**	**Avg.**
Area1	RSSI	0.021444	0.022087	0.021873
Area1	Static	0.022497	0.023300	0.022805
Area1	Dynamic	0.021673	0.022176	0.022052
Area2	RSSI	0.021388	0.022121	0.021844
Area2	Static	0.021706	0.022544	0.022031
Area2	Dynamic	0.022107	0.023295	0.022678
Area3	RSSI	0.022056	0.022663	0.022305
Area3	Static	0.021390	0.022363	0.022100
Area3	Dynamic	0.022434	0.023305	0.022739

(2) Balance Index

The balance index introduced in [4] is adopted in this experiment in order to quantify the performance of load redistribution. Suppose B_i is the total throughput of AP i, then the balance index β is defined as follows, where n is the total number of APs. The balance index is 1 when all APs have exactly the same throughput and gets closer to $1/n$ then the APs are heavily unbalanced.

$$\beta = \left(\sum B_i\right)^2 / (n * \sum B_i^2) \tag{17}$$

TABLE VI shows minimum, maximum and average balance index of both Static Selection and Periodic Dynamic Selection Algorithms compared to the RSSI algorithm for the three different STAs location areas. From the result it can be noted: through periodic dynamic selection algorithm, the balance indexes are all highly improved compared with RSSI algorithm in the three location areas. It confirms that the proposed strategy can significantly balance network load across APs.

TABLE VI. MIN.,MAX.,AVG.BALANCE INDEX

Location	Algorithm	Min., Max., Avg. Balance Index		
		Min.	**Max.**	**Avg.**
Area1	RSSI	0.637	0.669	0.6482
Area1	Static	0.625	0.644	0.6368
Area1	Dynamic	0.803	0.993	0.9288
Area2	RSSI	0.527	0.540	0.5326
Area2	Static	0.702	0.713	0.7078
Area2	Dynamic	0.676	0.973	0.9151
Area3	RSSI	0.395	0.400	0.3979
Area3	Static	0.566	0.591	0.5722
Area3	Dynamic	0.601	0.993	0.8622

VI. CONCLUSIONS

The paper proposes a strategy for differentiated access service selection based on network application, which are classified into four types according to their requirements on bandwidth and delay. Then, depending on the corresponding selection metric, a static access service selection is designed, which is enhanced by dynamic selection algorithms including periodic and aperiodic selection algorithm. Finally, simulations demonstrate that the strategy: (1) can provide differentiated QoS assurance to user of different type; (2) can effectively react to network condition changes and user's application changes in periodic and aperiodic mode; (3) can improve the network overall throughput and highly redistribute network load.

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