Access Points Can Tell More for Wiser Selection

Shibo Xu, Fengyuan Ren, Yinsheng Xu, Chuang Lin, Peng Cheng, Zixiao Jia
Tsinghua National Laboratory for Information Science and Technology,
Dept. of Computer Science and Technology, Tsinghua University, Beijing, China
{xshbo, renfy, xuysh08, clin, chengpeng5555, jiazixiao}@csnet1.cs.tsinghua.edu.cn

***Abstract*—Today, Wireless Local Area Networks (WLANs) have been extensively deployed in urban areas. It is common for users to face multiple Access Points (APs) when accessing Internet through WLANs, but difficult to make a wiser selection. The conventional approach of AP selection is based on the Received Signal Strength Indicator, which may lead to suboptimal performance due to its ignorance of the load on different available APs. The literature hasn't analyzed the effects of varying traffic patterns and transmission rates which affect the selection performance, and incur significant overhead to users. Although APs do have all details of the WLANs, they tell nothing useful to stations for selection. In this work, we comprehensively investigate the effects of varying traffic patterns and rates, and introduce some more useful selection metrics which can be deduced on the APs without any probe. Based on our investigation, we propose a scheme, by which APs can tell users more information for wiser selections without any modifications on user devices.**

Keywords—IEEE 802.11 WLAN, Access Point Selection, Traffic Pattern, Multi-Rate.

I. Introduction

In the last decade, Wireless Local Area Networks (WLANs) have been widely deployed. In WLANs, there are two types of devices, user devices (also known as stations) and Access Points (APs). Before data transmission, a station needs to associate with only one AP. It is common for users to face multiple APs when accessing Internet through WLANs. Therefore, a user has to select an AP.

The conventional AP selection is based on Received Signal Strength Indicator (RSSI), i.e., an incoming user always selects a WLAN with the highest RSSI. Although RSSI is an important indicator of channel quality between station and AP, it provides nothing about the load on different APs. Once the AP with highest RSSI is overloaded or associated with numerous stations, it may serve worse than the one with lower RSSI but fewer stations. Different APs can provide different bandwidths, which has no direct relation with RSSI. Therefore, RSSI-based AP selection is not an appropriate method, which may lead to poor throughput, imbalanced load and suboptimal performance [1] [2] [3].

Because users can't make wiser selections only by RSSIs, some more selection metrics are introduced in literature. In [4], the delay of packet transmission is regarded as a performance metric. [1] considers the number of associated stations and link quality. Virgil presented in [5] can get more precise information about the configuration and performance of network. In [2], the effect on the station and other stations when selecting an AP is analyzed. In [3], the potential bandwidth between station and AP is regarded as a metric, which is estimated through the delays of beacon frames.

However, the existing literature has not analyzed thoroughly the impacts of time-varying traffic patterns and multi-rate stations. In practice, these two types of heterogeneity (traffic patterns and rates) are rather ubiquitous in WLANs, and they do affect the network performance. In one hand, different users and applications produce different traffic patterns, besides the traffic distribution of each station is time-varying. On the other hand, the transmission rates of diverse stations are also different and time-varying. WLANs consists of a series of half-duplex over-the-air modulation techniques, which are defined by different sub-standards, including IEEE 802.11a/b/g/n [6] used in commercial products, and IEEE 802.11ac/ad [7] under development. These various sub-standards support different maximum physical bitrates. Even for the same sub-standard, data rate of per stream may also vary. Stations can dynamically adjust transmission rates depending on the channel conditions. Hereinafter, we call it *multi-rate*, no matter it results from different modes (802.11a/b/g/n), different surroundings (distance/interference), or different performance (CPU/memory). As validated by our experiments, the available bandwidths are different under different background traffics or different rate distribution.

Furthermore, to get performance metrics of AP selection, [3] and [5] send packets to middleware or destination, inducing extra overhead. The implementations of [3] and [4] require modifications on stations. New components are developed and deployed in [1] [2] [5]. The IEEE 802.11k and 802.11v introduce relevant functions for measurement and management, which haven't been widely deployed. As a whole, the literature has not studied thoroughly the influence of diverse traffic patterns and multi-rate stations. Besides, they introduce probing overhead to network and users. Modifications on stations are needed for implementation, which is inappropriate for self-configured users. The practical solution for AP selection is to conduct modifications only on APs, which will simplify the implementation and deployment.

In the conventional RSSI-based scheme, the RSSI is sensed by stations rather than APs. Namely, APs can not tell stations any useful information for comparison and selection, although they do possess those information. In other words, if APs can tell more useful metrics, it is feasible for stations to make a wiser selection with better performance.

In this work, we first validate the impacts on AP selection, which may result from traffic pattern heterogeneity and rate heterogeneity of the WLAN. Second, the impacts of these two types of heterogeneity are analyzed and quantified. Third, more useful metrics are deduced to indicate the performance that an incoming station can achieve when associating. Next, we propose an enhancement scheme to optimize the performance of AP selection, which is implemented on an off-the-shelf platform. Finally, we validate our scheme by experiments. The main contributions of this paper are twofold:

- We thoroughly analyze the impact of time-varying traffic patterns and multi-rate stations, and introduce new performance metrics based on existing information in APs.
- According to the analysis, a practical scheme is proposed to address the AP selection problem. This scheme can tell users more useful information for selection, which requires no modifications on user devices and no extra probing packets.

The paper is organized as follows. The motivation is presented in Section II. Section III analyzes the traffic pattern heterogeneity and its influence on AP selection. The influence of rate heterogeneity is analyzed in Section IV. The implementation of the proposed scheme is described in Section V. In Section VI, experiments are conducted to validate the proposed scheme. Finally, the paper is concluded in Section VII.

II. Motivation

In order to compare the gains of a new station when joining WLANs under different conditions, some experiments are conducted. The scenario is given in Fig. 1. Though there are many APs in the building, only three of them (red rounds) are available to the user. These three APs are all Buffalo WZR-HP-G300NH and operate in the same mode (802.11g+n).

A test server is set up to run test programs, such as web server and applications sending/receiving traffics. The test server is linked to APs by the wired part of the campus network. Because the rate of wired link is far more higher than WLANs, the bottleneck of the network lies in the wireless part. As more than 90% of traffics on the Internet are TCP-based [8], all of our test applications are based on TCP. Since WLAN users usually browse web, access online video or audio, or download files, three types of traffic patterns are configured, i.e. web, CBR and FTP.

- **Web traffic:** A web site is built on the test server. The whole size of its homepage is about 510KB. On stations, a java based performance measurement tool called Apache JMeter [9] is used, which can imitate multiple users simultaneously.
- **CBR traffic:** According to our survey, the rate of live broadcast of Euro 2012 from China Network Television (CNTV) is about 80$\sim$100KB/s. An application is developed, which can send constant TCP traffic at preset rate.
- **FTP traffic:** This type of traffic is also generated by our developed applications, which can record the goodput and the number of transmitted bytes to log files.

Three experiments are conducted. In Exp. 1 and Exp. 2, the incoming station associates with the nearer APs (AP1 and AP2, in this room). In Exp. 3, the station associates with the slightly far AP (AP3, in the next room). The stations associated with each AP is listed in Table I. All traffics are sent from the test server to stations. All stations operate in 802.11g mode, except that the FTP station of AP2 operates in 802.11b mode. Each of the web stations imitates 10 users. The access interval of each user is uniformly distributed between 1s and 10s. The incoming station associates with these APs respectively. After a successful association, the station starts a FTP traffic to download a file from the test server. The total bytes received by the station in one minute is shown in Fig. 2, and the result is the mean value of 10 times experiments.

TABLE I. APs and Stations

AP	RSSI	Stations
AP1	-26dBm	2 FTPs, 2 CBRs(100KB/s), 1 Web
AP2	-26dBm	1 FTP, 1 Web
AP3	-60dBm	1 FTP, 1 Web

Though AP1 and AP2 have equal RSSIs, different background traffics result in different load on them, and the available bandwidth of AP1 is less than AP2. Although AP2 and AP3 have equal traffic load, AP2 is associated with a low-rate station. Consequently, the available bandwidth of AP3 is the largest though its RSSI is the lowest. So, only by RSSI we may not make a wise choice.

Since all traffics pass through the AP, it knows about most status of the WLAN. Some useful metrics can be directly deduced from these status information without any overhead to the network. Additionally, since the selection decisions are usually made by users/stations, how to convey these metrics to users/stations forms another problem. In most of the existing schemes, some fields are added to certain frames like beacons. To identify these metrics, some modifications are needed on the stations. So, another new mechanism is needed to inform users whose devices are unmodified.

The goal of this paper is to find more useful performance metrics for AP selection, which can indicate the impacts of time-varying traffic patterns and multi-rate stations. These performance metrics can be obtained from existing information in APs without any extra overhead like probing. Based on these metrics, WLAN users are capable of selecting APs for better performance.

The two types of heterogeneity mainly comes from two aspects: user behavior and station condition (type, mode and surroundings). The former leads to different traffic patterns, the latter results in different transmission rates, and they both affect the performance of AP selection. These two types of heterogeneity will be studied in the following sections.

III. Traffic Pattern

Since it's difficult to model the traffic distribution in practice, we study relevant factors by experiments and analysis. In this section, we first validate the effect of different traffic patterns. Then, we analyze possible factors that will affect the selection performance.

A. Comparative Experiments

To check the impact of different background traffics, four experiments have been performed with two type of APs, i.e., Cisco LinkSys WRT54g and Buffalo WZR-HP-G300NH.

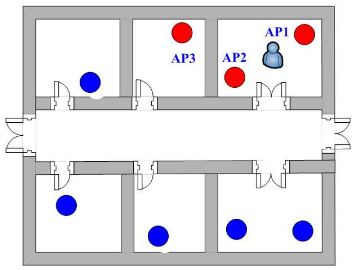

Fig. 1. Experiments Scenario

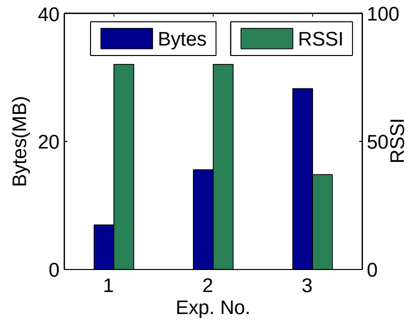

Fig. 2. Bytes received from different APs

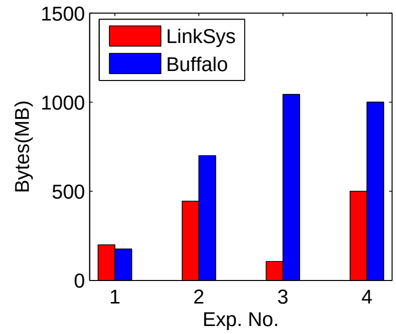

Fig. 3. Bytes Received under Different Traffics

TABLE II. BACKGROUND TRAFFIC

Exp.	Background Traffic
1	4 FTPs
2	4 CBRs(1KB per 10ms)
3	4 Burst(500KB per 5s)
4	4 Burst(1000KB per 10s)

In each experiment, four homogeneous background traffics start firstly, then the incoming station joins the WLAN and downloads a file using FTP. The background traffics for each experiment are listed in Table II. The bytes received by the incoming station in 10 minutes under different background traffics are depicted in Fig. 3.

Generally, in a WLAN, a station with empty queue is called *silent*. Otherwise it is called *active*. In Fig. 3, the gain of the incoming user is the least when background traffics are all FTPs (except for Exp. 3 by the old WRT54g AP). Since all background stations are active all through the experiment, they compete with the incoming station from start to end. Therefore, the bandwidth obtained by the incoming station is about a fair share of the total capacity. If the background traffics are all CBRs, and their rates are less than the capacity, each of them can be considered as an ON/OFF traffic with a small OFF duration. The station is silent when traffic is in OFF status, and active when traffic is in ON status. Hence, the competitiveness or aggressiveness of continuously active stations is stronger than occasionally active stations. It's similar to the burst traffic, which can be also regard as an ON/OFF traffic.

Although the total bytes generated by the CBR and burst traffics are equal, their competitiveness is different as shown in Exp. 2, 3 and 4. An interesting phenomenon is that the influence of traffic patterns is also relevant to the types of APs, which may result from the different buffer sizes. For the old WRT54g, the memory size is 32MB while it's 64MB for WZR-HP-G300NH. Larger memory enables WZR-HP-G300NH to tolerate more bursts. Recall that the bottleneck of the network is wireless link. If the bursts are large enough to fill the AP's buffer, incoming packets will be dropped. Consequently, the TCP connection will enter the *fast recovery* or *slow start* phase. Since most APs only have shallow buffers, more frequent and larger bursts of background traffics will cause worse degradation. Thus, the selection performance depends greatly on the traffic distribution.

In the following subsections, the diversity of different background traffics is analyzed. Under the same background traffics: 4 FTPs, 4 CBRs (100KB/s), 4 webs (500KB per 5s), we collect information from AP (WZR-HP-G300NH) for 10 minutes. Then, based on the statistical data, we study the features of different background traffics.

B. Number of Active Stations

Wireless is a shared media, and the MAC layer of IEEE 802.11 intends to distribute transmission opportunity among active stations fairly. Hence, the number of active stations (denoted by n) is not only an effective indicator of AP's load, but also an important metric of potential transmission opportunity. Next, we will discuss how to estimate the parameter n.

Since traffics of stations are time-varying, the only method to estimate n is to divide the duration into some timeslots and then count it in each timeslot. If the timeslot is too long, most stations will be considered active, including the silent ones that send or receive a packet occasionally. If the timeslot is too short, some active stations will be ignored because of failures in competition and transmission. Thus, the length of the timeslot must be long enough to contain all the active stations. In other words, every active station can transmit at least one packet in each timeslot, which maintains the fairness of DCF. In fact, DCF is fair for long term, and unfair for short term [10]. So, the timeslot must be relatively long.

Allowing each active station transmitting at least one packet, the length of timeslot is also proportional to the number of active stations. Hereinafter, the timeslot is called time window (T_{wnd}), because its length changes according to the number of active stations. In order to keep fairness for variable numbers of stations, a unit-window T_{unit} is introduced. If the number of active stations is n, then the time window will be

$$T_{wnd} = n \times T_{unit}. \quad (1)$$

Where n is the number of stations which have sent or received at least one data frame in the duration of T_{wnd}. Obviously, T_{wnd} and n are interdependent. In WLANs, the number of associated stations is limited. Besides, the number of active stations will not change greatly in a short time. Consequently, the parameter n in the previous T_{wnd} can be used to calculate this T_{wnd}.

The distribution of n of different background traffics is given in Fig. 4. To count n and other parameters like mean and variance of frames, and the minimum rate in subsequent

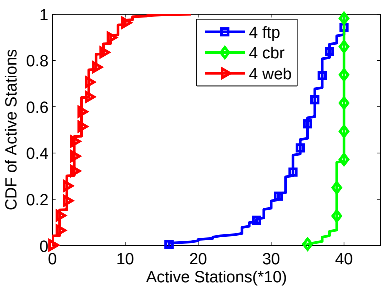

Fig. 4. CDF of n of Different Traffics

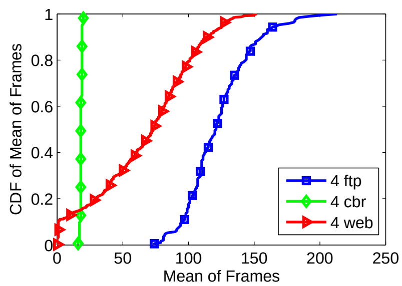

Fig. 5. CDF of Average Frames

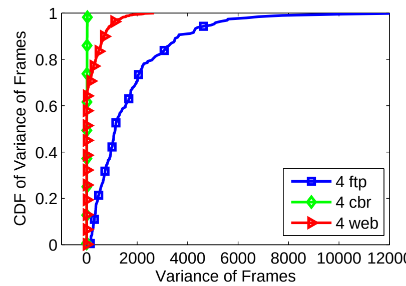

Fig. 6. CDF of Average Variance of Frames

sections, we take a time window as one round. A sampling period consists of 20 rounds. When a sampling period completes, we calculate the mean values of these 20 rounds. T_{unit} in these experiments is set to 50ms.

As shown in Fig. 4, the average n of FTP and CBR traffics (between 3 and 4) is more than web traffics (less than 1), which means that the incoming station will obtain more transmission opportunity when the background are web traffics. It is interesting that n of 4 FTP flows is less than that of 4 CBR flows, which results from the queue in the AP. Since the bottleneck is the wireless link, the queue of the AP will be filled constantly with FTP traffics. If some packets of a flow are dropped, it will cost some time for its packets arrive again. Namely, the packets of FTP flows are transmitted in bursts. Therefore, we further investigate other factors that can indicate the load of APs more precisely.

C. Traffic Statistics

Although n is a performance indicator, it can't indicate precisely the competitiveness of the aggregate traffic. For example, if the frames transmitted by four stations in a round are $\{5, 1, 1, 1\}$, and $\{2, 2, 2, 2\}$ in another round. Intuitively, one may think that the competitiveness of the aggregate traffic in the latter round is stronger than that in the former one. In the former round, only one station is active in most part of the duration, while in the latter round, four stations are all active during the time window. It's not always true that DCF is absolutely fair in the real world. Hence, some correction is needed to estimate AP load more precisely.

The Cumulative Distribution Function (CDF) of average frames sent or received by each station in all sampling periods is given in Fig. 5. It is shown that though n of 4 FTP flows is less than 4 CBR flows, the average number of frames is more than CBR flows. Actually, the products of n and average number of frames are about 4172,723,277 respectively for FTP, CBR and web traffics, which indicate AP load more precisely than n. If there are two close n, the competitiveness of the aggregate traffic with more frames will be stronger. In other words, both n and frames should be taken into consideration to indicate the load of APs. In Fig. 6, the variance of frames under 4 FTP flows is the largest. It means that the transmission opportunity of FTP flows is unfair in a short interval. The variance is also an indicator of bursts.

In order to deduce the transmission opportunity available for the incoming station, we analyze the holding time of stations in the following section. Obviously, when a station get the transmission opportunity, the time it spends on transmission is related to the rate and packet size. However, as validated by our experiments, only when stations are transmitting at very low-rate, can the packet size impact the performance. Hence, we turn to analyze only the factor of rate.

IV. Variable Multi-Rate

Variable multi-rate is ubiquitous in WLANs. First, backward compatibility of IEEE 802.11 allows coexistence of devices with different sub-standards. As mentioned in [11], the impact of legacy stations to the WLAN or other stations is drastic. Second, due to the effect of channel conditions like interference, the rate adaption of IEEE 802.11 allows different stations transmitting at different rates at different time. The impact of low-rate stations is just like the legacy stations. In this section, we utilize experiments to address effect of multi-rate stations, and propose an appropriate performance indicator for variable muti-rate.

A 802.11g station A is used to compete with another station B. The FTP download goodput of station A in one minute is depicted in Fig. 7 with mean value of five times experiments. The top blue dashed line is the goodput when station A monopolizes the wireless bandwidth. The blue solid line is the goodput of station A when B is also downloading FTP traffic in 802.11g mode. Obviously, the goodput of A is about half of when A monopolizes the link. However, if B is in 802.11b mode, the goodput of A decreases quickly to the bottom red line. Besides, the goodput of 802.11g is no better than 802.11b (the black line). Even the traffic of B is negligible, i.e., one packet of 1KB per 5 seconds. The goodput degradation of A is still obvious as shown by the green line. Because the high-rate stations behave just like the lowest rate station when they coexist, the lowest rate can be regarded as the upper bound of transmission rate for all active stations. Hence, the lowest rate is an appropriate throughput indicator, which is discussed subsequently.

Due to traffic diversity, the status of stations may transit between active and silent frequently. If the low-rate station stays in silence, it will not impact other high-rate stations. Hence, to get the lowest rate, the traffic patterns must be taken into consideration concurrently. Since the transmission rate of a station is time-varying, we still adopt the similar methodology used in Section III to compute rates. First, we obtain the average rate of each station in a round, which is the mean value of rates of all frames sent or received by the station in this time window. Second, we obtain the minimum

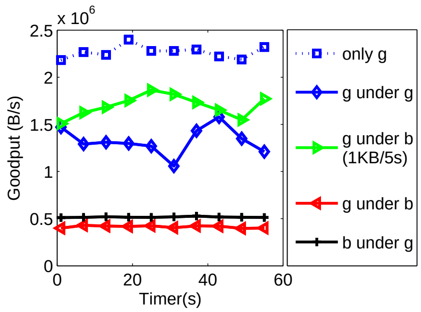

Fig. 7. Goodput of Station A When Competing with B of Different Rates

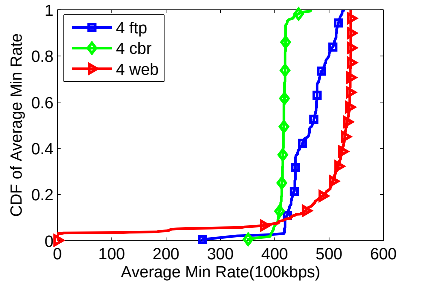

Fig. 8. CDF of Average Minimum Rate of 4 802.11g Stations

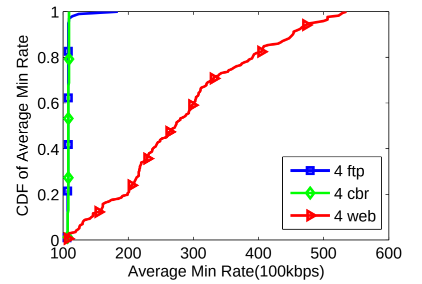

Fig. 9. CDF of Average Minimum Rate of 1 802.11b and 3 802.11g Stations

rate during one round, which is the minimum value of average rates of all stations in that round. Finally, we take the average minimum rate in a sampling period as a sample, which is the mean value of the minimum rates in 20 rounds.

To investigate the average minimum rates of different background traffics, three experiments are conducted under 4 FTPs, 4 CBRs and 4 web traffic (same as in previous section). First, all of the four stations operate in 802.11g mode, and the CDF of average minimum rates is given in Fig. 8. Then, one of the four stations changes to 802.11b mode, and the CDF of average minimum rates is given in Fig. 9. If the transmission rates of all stations are equal, they will not affect each other. Once some stations transmit at a lower rate, the performance of all high-rate stations will degrade. Since the active time of FTP and CBR traffics is much longer than that of web traffics, the degradation is also larger than that of web traffics. Therefore, the average minimum rate is an appropriate throughput indicator, which is capable of expressing both traffic patterns and variable multi-rate.

V. Implementation of the Scheme

Now, we have got some more useful performance metrics from above sections, such as n, load and average minimum rate. In this section, we will discuss how to convey them to users and how to implement these methods.

A. The advertisement mechanism

An advertisement mechanism is needed to broadcast more metrics to users and stations. We hope that even though stations have not been modified, their owners can also make an intelligent decision by our metrics. Since the only information users can see are SSIDs and RSSIs, the RSSIs are sensed by the stations and not provided by the APs. Then, the only way to inform common users without any modification on their devices is to make use of the SSIDs. Although SSID can be 32 characters at most, in most cases, it is not longer than 20 bytes. That is to say, there are at least 10 bytes can be used to convey more useful information.

The key idea of the advertisement mechanism is to encode performance metrics in SSIDs. To keep the identification function of SSID, a tag is introduced to separate the ID and metrics. The tag can be one, two or more especial characters. To prevent being used in SSIDs, the tag has better to consist of more than one character. In this paper, "=>" is taken as the tag. Let's suppose the metrics are "XYZ", and the initial SSID of a WLAN is "$MySSID$", then the new SSID will be "$MySSID => XYZ$". Note that the metrics are variable, so the new SSID is dynamic. The initial SSID of the WLAN is the common prefix for all dynamic SSIDs. The overhead of this mechanism is acceptable. Because in one hand, no more than 10 bytes are added to the beacon and probe response frames. On the other hand, the number of the beacon and probe response frames is far less than that of data frames.

To a user, the SSID is only useful when he scans WLANs and selects a WLAN. After the user joins a WLAN, the SSID is useless to him. Because the station checks the frames from the AP by the source MAC address, not by the SSID. So, the changes of the SSID will not impact the associated stations. Besides, the station will not change its AP unless the AP is unusable or the owner enforces a switchover.

To an AP, it checks the association requests from stations by the SSID. If the SSID provided by a station does not match that in the AP, the AP will refuse the station. In the proposed advertisement mechanism, it is easy for the AP to identify whether a SSID comes from it or not. If the SSID provided by a station has the same prefix as the AP, the AP will accept the station.

B. Implementation

Based on the performance metrics and the advertisement mechanism mentioned above, the proposed scheme consists of two parts. In the first part, the AP extracts the metrics (n, load and average minimum rate) from existing information, without any probe. In the second part, the AP informs users of these metrics by the advertisement mechanism. Then, users can make an intelligent decision by RSSIs and these metrics. In this section, we will describe the detailed implementation of the proposed scheme.

This scheme is implemented in Buffalo WZR-HP-G300NH wireless router. First, we flash the router with DD-WRT [12] open source firmware. Then, in Ubuntu 10.04 LTS, we download the latest source files (backfire) of OpenWRT [13], and compile files to an image file. Finally, we flash the image file to the router through TFTP. If some new functions are needed, we add some codes to the source files. Subsequently, we re-compile the source files and flash the image file to the router, or just install/update the relevant modules.

In OpenWRT, the AP function is implemented in HostAP module, which runs as an application in the user space.

The HostAP module deals with the association, authentication and probe. To accept associations whose SSID prefixes are in accordance with the AP's initial SSID, some codes for comparison are replaced. The IEEE 802.11 MAC protocol is implemented in mac80211 module, which runs in the kernel space. The mac80211 module mainly handle transmission and receipt of frames. So, statistics of n, frames and minimum rate is handled in this module.

To implement the dynamic SSIDs, the beacon frames and probe response frames are modified. The probe response frames are generated by the HostAP module, while the statistic information is in the mac80211 module. In order to avoid the troublesome of data exchange between the user space and the kernel space, the probe response frames are modified in the mac80211 module. When a probe response frame is passing by, the mac80211 module appends the dynamic metrics to the SSID field. The beacon frames is scheduled by a timer in the physical layer, while the frames are packaged also in the mac80211 module. So, modifications of probe response and beacon frames are implemented in the mac80211 module.

For traffic statistics, an array and a timer are added to the mac80211 module. The number of frames ($iFrames$) and the sum of rates ($iSumRate$) for each station are included in the array. When a station sends or receives a data frame, the corresponding $iFrames$ increases by 1 and $iSumRate$ increases by the transmission rate of this frame. The timer is set for a time window. When the timer expires, parameters are calculated. Afterwards, $iFrames$ and $iSumRate$ are reset to zero. Finally, the new time window is obtained by Eq. (1), and a new timer is set.

The calculation of parameters is provided hereunder. n is the number of stations with $iFrames > 0$. The mean and variance of frames obtained by Eq. (2) and (3).

$$FrameMean = \frac{\sum_{i=1}^{n} iFrames}{n} \quad (2)$$

$$FrameVariance = (Frames - FrameMean)^2 \quad (3)$$

The average rate of each active station is obtained by Eq. (4).

$$AverageRate = \frac{iSumRate}{iFrames} \quad (4)$$

Then the minimum average rate in this round is the minimum $AverageRate$ of all stations, as given in Eq. (5).

$$MinAverageRate = \min\{AverageRate_i, i = 1...n\} \quad (5)$$

When 20 rounds complete, the mean values of n, $FrameMean$, $FrameVariance$ and $MinAverageRate$ are calculated, which are regarded as sampling results in one sampling period. Even so, the metrics obtained in sampling periods may be dramatically changeable, which are not convenient to users in AP selection. Hence, we take Exponentially Weighted Moving Average (EWMA) over all metrics. After EWMA, these metrics will be informed to users for AP selection.

VI. VALIDATION

Some more experiments are conducted in a conference center, where has some meeting-rooms side by side. One AP is set in each room. In Room 1, six students access the network (test server) through WLANs. The traffic types are 2 FTPs, 2 CBRs (100KB/s) and 2 webs (500KB/5s). According to the traditional RSSI-based scheme, they all associate with the AP (AP1) in this room, the RSSI of which is about -30dBm. There is another AP (AP2) available in Room 2, the RSSI of which is about -55dBm. There are also some other APs in the building, since their RSSIs are so weak, and we neglect them. These students join the WLAN one after another. If they use the proposed scheme, they will select the preferable AP according to an selection policy. The selection policy is given below.

A. A Simple AP Selection Policy

By means of the proposed scheme, now users have got RSSIs, n, load and average minimum rates (min_rate) of all available APs. First, we find via experiments that the relationship between RSSI and performance is not linear. Only when RSSI goes below a certain level (such as -70dBm, we call it degradation threshold), does performance begin degrading rapidly. If the RSSI is higher than the degradation threshold, the variation of RSSI will not impact the performance. Second, min_rate can be regarded as the transmission rate of the channel, which is shared by all active stations. So, min_rate/n is an approximate indicator of available bandwidth to any one of the active stations. Third, if the estimated available bandwidths of several APs are close, the preferable AP is the one with the least load. Accordingly, three rules are made for selection.

- **Rule 1:** exclude APs whose RSSIs are very weak.
- **Rule 2:** select the AP with the most available bandwidth.
- **Rule 3:** select the AP with the least load if more than one AP are left after Rule 2.

Based on these three rules, we compare the performance when the students use different schemes in the following two experiments. In Exp. 1, all station operate in 802.11g mode. In Exp. 2, one FTP station operates in 802.11b mode, while all others are in 802.11g mode.

B. Experiment 1

According to the proposed scheme, the first user selects AP1, and the second user selects AP2, no matter what traffic types they have. When the third user joins, he compares the metrics. As all stations are homogenous, the influence of multi-rate can be neglected. The main metrics are n and load of APs. When one or two stations associates with a AP, the load ($n * FrameMean$) is given in Fig. 10. As the average data rates of web and CBR traffics are approximate and far less than FTP. If both of the first two stations are FTP or not FTP, the third user will select AP1, or he will select the non-FTP one. The selection will go on until all users join in. The proposed scheme assure that the two FTP stations will not associate with one AP. Then, the worst case will be that 1 station associate with one AP, and 5 stations associate with the other AP. To achieve this situation, the first user and the last user must be FTP traffic.

After these six users join, we compare the average bytes transmitted by the two FTP flows. The experimental result at the worst is given in Fig .11, and the performance of FTP flows

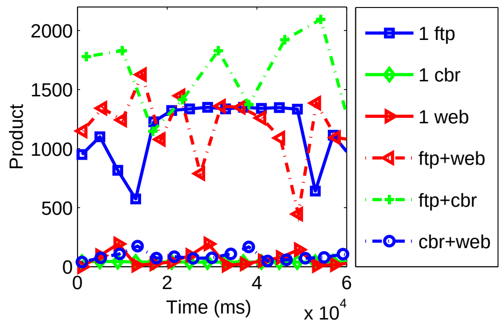

Fig. 10. Load Under Different Traffics

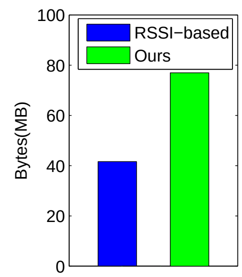

Fig. 11. Average bytes of 2 FTP flows

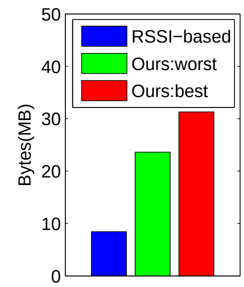

Fig. 12. Average bytes of 2 FTP flows

is nearly doubled. Because the bandwidth is mostly occupied by FTP flows, the performance of CBR and web flows are not improved obviously.

C. Experiment 2

To validate the impact of multi-rate stations, we adopt a simple way, namely heterogeneous stations. Since it's hard to manipulate the surroundings to trigger rate adaption. According to the proposed scheme, the best case is the 802.11b station associates with one AP, while the other 5 stations associate with the other AP. Since in this case, the low-rate station has no impact on other high-rate stations. In the same way, the worst case is that the 802.11g FTP station associates with one AP, while the other 5 stations (including the 802.11b station) associate with the other AP. If the 802.11g FTP is the first station and 802.11b is the last station, it will be the worst case. If the 802.11b is the first station and 802.11g FTP is the last station, it will be the best case. We compare the performance of the conventional scheme and the two cases of the proposed scheme. The experimental result is given in Fig. 12. Since the high-rate FTP gets rid of the containment from the low-rate one, the amount of bytes transmitted by the two FTP flows is raised by about 3 times.

From these two experiments, the proposed scheme can improve the performance a lot. The improvement is not only to users, but also to the WLANs. Since it can distribute the load across multi APs. The improvement will be greater with more users and more APs.

VII. Conclusion

Due to different devices, different conditions and different users, the heterogeneity of traffic patterns and rates is increasingly ubiquitous, which impacts the performance of AP selection greatly. Based on extensive experiments and analysis, this paper analyzes thoroughly these two types of heterogeneity and deduces more useful metrics to assist making decisions. To inform users these more useful metrics, an advertisement mechanism is proposed. Finally, a new scheme for AP selection is implemented. By which, any user can make a wiser selection without any burdensome.

VIII. Acknowledgments

The authors gratefully acknowledge the anonymous reviewers for their constructive comments. This work is supported in part by the National Grand Fundamental Research Program of China (973) under Grant No.2012CB315803 and 2010CB328105, and the National Natural Science Foundation of China (NSFC) under Grant No.61225011.

References

[1] S. Venkatesan and C. Manoharan, "Access Point Selection in WLAN using Optimal Association Control Algorithm," *European Journal of Scientific Research*, vol. Vol.60 No.2, April 2011.

[2] M. Abusubaih, J. Gross, S. Wiethoelter, and A. Wolisz, "On Access Point Selection in IEEE 802.11 Wireless Local Area Networks," in *WLN 2006*.

[3] S. Vasudevan, K. Papagiannaki, C. Diot, J. Kurose, and D. Towsley, "Facilitating Access Point Selection in IEEE 802.11 Wireless Networks," in *Internet Measurement Conference 2005*, October 2005.

[4] V. A. Siris and D. Evaggelatou, "Access Point Selection for Improving Throughput Fairness in Wireless LANs," in *10th IFIP/IEEE International Symposium on Integrated Network Management, 2007*.

[5] A. J. Nicholson, Y. Chawathe, M. Y. Chen, B. D. Noble, and D. Wetherall, "Improved Access Point Selection," in *MobiSys'06*.

[6] "Ieee std 802.11 part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications," 2012.

[7] [Online]. Available: http://www.ieee802.org/11/

[8] T. Karagiannis, M. Molle, M. Faloutsos, and A. Broido, "A nonstationary Poisson view of Internet traffic," in *INFOCOM 2004*, March 2004.

[9] [Online]. Available: http://jmeter.apache.org/

[10] M. Bredel and M. Fidler, "Understanding Fairness and its Impact on Quality of Service in IEEE 802.11," in *INFOCOM 2009*, April 2009.

[11] D. Gong and Y. Yang, "AP Association in 802.11n WLANs with Heterogeneous Clients," in *Infocom 2012*, March 2012.

[12] [Online]. Available: http://www.dd-wrt.com/

[13] [Online]. Available: http://openwrt.org/