Traffic-aware Decentralized AP Selection for Multi-Rate in WLANs

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***Abstract*— AP selection problem is one of the major issues in infrastructure WLANs. Recently, many authors in the literatures have proposed a novel AP selection scheme which can provide better performance (e.g. aggregated throughput, load balancing) than RSS-based legacy scheme. However, they have presented the schemes with non-practical assumptions, e.g. they have assumed that adjacent APs are configured with orthogonal channels and each station transmits the data frame using a single data rate. As we have studied, adjacent BSSs' transmission and multiple transmission rates impact the network's performance. In this paper, we propose a practical traffic-aware AP selection scheme considering the factors previously mentioned. By exploiting the Retry field in the MAC header as feedback about channel conditions, we can infer the network conditions, and each client can select the 'best' AP in terms of expected throughput. We demonstrate the effectiveness of our solution by comparing to existing approaches through ns-2 simulation.**

***Keywords*— IEEE 802.11 WLANs; AP selection; RetryRatio; multiple transmission rates; adjacent BSSs' transmission;**

I. Introduction

Recently, as the deployment of IEEE 802.11 WLANs is going rapidly, we can use wireless equipments ubiquitously. They provide mobility, convenience, flexibility and tolerable throughput compared to wired equipments.

In infrastructure WLANs, a client associates with a single AP that coordinates all traffic in a downlink or uplink manner. Then AP selection is an important issue, which prominently impacts the system performance including throughput, fairness and QoS (Quality of Service), etc. However, how to select an appropriate AP is not specified in current IEEE 802.11 standard, so manufacture vendors usually adapt AP selection scheme based on the RSSI (Received Signal Strength Indication) [1]. After scanning the channels, a client selects the AP from which it receives frames with the strongest signal strength.

As we have studied, such a RSS-based AP selection scheme cannot support the best throughput performance as shown in [4]-[14]. This legacy scheme leads to imbalance of system performance. The legacy scheme results in concentration on specific APs, i.e. many clients may associate with a few APs, because they have received the frames with the strongest signal strength from those APs. So many works [4]-[11] have presented the improved AP selection schemes, but their proposed AP selection schemes have got non-practical assumptions: authors have assumed that each station uses same transmission rate and adjacent APs are configured with different non-overlapping channels.

Instability of medium due to fading and multi-path, and the limited number of orthogonal channels are inherent to WLANs. To cope with the variation of wireless channels and achieve higher spectral efficiency, the current 802.11 PHY provides a wide range of data transmission rates between 1Mbps and up to 54Mbps in IEEE 802.11a/g and up to 11Mbps in IEEE 802.11b [1]. Our interest in this work is not Rate-Adaptation, but the impact of Rate-Adaptation on the overall performance of multiple transmission rates in WLANs. As pointed out in [3], when some stations use a lower data transmission rate than that of the others, the performance of all stations is considerably degraded. When a slower station captures the channel for a long time, it penalizes faster stations; the faster stations' throughput is down-equalized to the slowest station's throughput. This phenomenon is defined as rate-anomaly. Moreover, the limited number of orthogonal channels (e.g. 3 channels in the 802.11 b/g, 12 channels in the 802.11a) results in Co-Channel Interference among the adjacent BSSs (Basic Service Set). These adjacent BSSs' transmission that is called inter-BSS interference can result in performance degradation.

The main challenge of designing the practical AP selection scheme is accurately estimating channel conditions (e.g. the number of active clients and busy intensity) as well as getting practical assumptions. Nevertheless, most previous works [4], [7], [8], [10], [11] have got non-practical assumptions: they did not consider multiple transmission rates and adjacent BSSs' transmission. Only a few papers [9], [12], [13] have considered multiple transmission rates, but still without adjacent BSSs' transmission. Authors of [14] have considered both of them, but did not reflect these factors perfectly.

In this paper, we present a more realistic approach to AP selection, i.e. we propose a novel traffic-aware AP selection scheme considering multiple transmission rates as well as adjacent BSSs' transmission. By exploiting the Retry field in the MAC header, we can estimate the transmission failure probability which is related to the number of active clients in each BSS implicitly as shown in [15], and we derive the expected throughput at client side, i.e. the maximum achievable throughput when associating with a target AP. We demonstrate the effectiveness of our solution by comparing to existing approaches through ns-2 simulation [17].

The remainder of the paper is organized as follows. Section 2 reviews the related work. Formulation of the proposed AP selection scheme is presented in Section 3. Section 4 shows the performance evaluation through ns-2 simulation, and finally the paper concludes with Section 5.

II. RELATED WORK

Many works [4]-[14] have shown that the legacy AP selection scheme leads to poor performance in terms of achievable throughput and load balancing; they have proposed an improved AP selection scheme considering traffic-aware in each BSS. There are two kinds of approaches about AP selection: centralized and decentralized approaches. In the former, wired equipment such as an AP or an intelligent management system connected to the WLANs controls communication between APs and clients, and collects information such as the number of clients and busy intensity. Such centralized architectures have been proposed in [5], [6]. However, when the wired equipment is broken down, the system cannot provide service at all. Moreover, the link between APs and the wired equipment might be bottle-neck potentially. On the other hand, all clients using decentralized approach [4], [7]-[14] select the best AP based on various information piggybacked in the management frame or in self-recognized manner, instead of centralized help [5], [6].

In [7], two new dynamic association schemes have been proposed. The first scheme considered channel conditions in both uplink and downlink to each AP as well as load at each AP. The second scheme combined this information with the routing information of packets from a candidate AP to the destination. Although the scheme did exploit an airtime cost metric, these schemes did not consider multiple transmission rates and adjacent BSSs' transmission.

Authors of [8] have proposed an AP selection scheme based on both the number of clients and wireless channel conditions rather than RSSI. However, they have assumed same data transmission rate for all clients: they did not consider multiple transmission rates. Authors of [9] have proposed AP selection scheme considering hidden terminal effect, by exploiting the QBSS Load information in IEEE 802.11e standard. But authors did not consider the adjacent BSSs' transmission. Reference [10] described the methodology by estimating probe delay time in active scanning. Reference [11] described the methodology by estimating the potential bandwidth based on the delays experienced by beacon frames. However, AP selection schemes in [10], [11] have considered neither multiple transmission rates nor adjacent BSSs' transmission. In [12], authors have proposed an AP selection scheme which considered the theoretical throughput as well as its impact on already associated clients. But authors of [12] have assumed single-hop environment adopted by Bianchi's model, so they did not consider the adjacent BSSs' transmission. In [13], authors have proposed an AP selection scheme only considering the multiple transmission rates. Reference [14] has proposed the metric of "expected throughput" that combined AP capacity in the presence of interference, the aggregated transmission delay of all existing clients and the transmission rate of a new client. They considered the two factors previously mentioned. However, they assumed the traffic was fully saturated downlink; in case of uplink traffic, their proposed metric is not working properly, since the measurement value of ATD (Aggregated Transmission Delay) has large variations. The ATD is directly related to the number of active clients.

III. PROPOSED AP SELECTION SCHEME

A. System Model

We consider large-scale WLANs densely deployed which consists of many APs and clients. All APs operate on infrastructure mode and are connected to wired networks.

For the medium access, we consider only DCF (Distributed Coordination Function); all stations access the channel based on CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance) protocol. All transmissions in each BSS are made by an AP, i.e. either downlink or uplink. The traffic is generated only from a client to its AP. The transmission rate of a client is decided only by the distance between the client and its AP.

We assume perfect channel conditions, i.e. no packet loss, and also assume that no station resorts to RTS/CTS mechanism due to high overhead.

B. Metric Formulation

The expected throughput of each client is defined as the inverse of average transmission time including all retransmissions until a data is transmitted successfully. We define the concept of successful data transmission along with the frame exchange sequence of DCF mode in 802.11 WLANs [2], [4].

When a data frame arrives at the head of the queue but the channel is busy, the MAC waits until the medium becomes idle. If the channel becomes idle during the DIFS (DCF InterFrame Space) duration, the MAC starts the backoff mechanism. As long as the medium stays idle, a random backoff counter is decremented. When the backoff counter reaches zero, sender tries to transmit the data frame. For each successful reception of a data frame, the receiver immediately acknowledges the data frame reception by sending an ACK frame; the ACK frame is transmitted after SIFS (Short InterFrame Space) duration. If the ACK frame is successfully transmitted, the procedure of a data transmission is over [1], [2], [15].

Keeping the concept mentioned above in mind, we define the expected throughput as follows. The average transmission time until a client k transmits a data frame successfully to AP i is referred to as $\overline{T_{k,i}}$; the expected throughput is then given by:

$$\text{expected throughput}(\theta_{k,i}) = \frac{1}{\overline{T_{k,i}}} \quad (1)$$

The average transmission time until a data frame is transmitted successfully can be derived easily by exploiting analysis of [12]. Above (1) does not consider retransmissions due to collision between stations. $T_{k,i}(j)$ denotes the average transmission time until client k transmits a data frame of length L to AP i successfully, after j^{th} retransmission due to collision, and is given by:

$$T_{k,i}(j) = tDIFS + tbackoff(j) + tDATA + tSIFS + tACK$$

$$tDATA = tPreamble + tHeader + \frac{l_{macheader} + l_{payload}}{rate(k)}$$

$$tACK = tPreamble + tHeader + \frac{l_{ack}}{rate_{basic}} \quad (2)$$

where *rate(k)* is the data transmission rate of client k; *tDATA* depends on the data transmission rate of client k. $l_{macheader}$, $l_{payload}$ and l_{ack} denote length of MAC-header, payload and ACK frame respectively. All the control frames such as ACK, RTS (Request to Send) and CTS (Clear to Send) are transmitted at the basic rate according to 802.11 standard; in case of 802.11b, the basic rate ($rate_{basic}$) is 1Mbps. *tACK* is the duration of the ACK frame, *tDIFS* is the DCF InterFrame Space and *tSIFS* is the Short InterFrame Space.

The contention window takes an initial value of CW_{min} according to 802.11 standard. If a data transmission attempt fails, the value of *CW* is doubled until it reaches CW_{max}. Once it reaches CW_{max}, the value of *CW* remains CW_{max} until the transmission successfully goes to an end or the frame is discarded due to Retry limit, and *CW* is reset. This improves the stability of the access protocol and the performance under congestion conditions. The backoff interval randomly draws an integer number from a uniform distribution over the interval [0, *CW*] [1], [2], [4].

tbackoff(j) denotes the average backoff time during consecutive j^{th} transmission attempts as follows:

$$tbackoff(j) = \frac{2^j \times (CW_{\min} + 1) - 1}{2} \times E[slot\ time] \qquad 0 \le j < 6$$

$$= \frac{CW_{\max}}{2} \times E[slot\ time] \qquad j \ge 6 \quad (3)$$

When *tbackoff(j)* is calculated, we should consider the following: the IEEE 802.11 standard [1], [2] depicts, in its section 9.2.5.2, how the backoff counter is decremented. If the medium is busy at any time during a backoff slot, then the backoff procedure is suspended. We assume that a station has a backoff counter equal to a value b. If the current medium slot-time is idle, at the end of slot-time the backoff counter is decremented, and the station will start the next slot-time with backoff counter b-1. On the other hand, if the current medium slot-time is busy, the station will freeze the backoff counter at b: the backoff counter is decremented only during idle slots. When we calculate *tbackoff(j)*, slot-time does not denote physical slot time, but virtual slot time.

E[slot time] is the expected length of a slot-time; it is adopted from virtual slot time of Bianchi's model [16] to be given by:

$$E[slot\ time] = P_{idle} \times \sigma + P_{tr} \times P_c \times T_c + P_{tr} \times (1 - P_c) \times T_s$$

$$P_{idle} = \frac{\sum \sigma}{T} = 1 - P_{tr}$$

$$T_c = tDATA_{slowest} + tEIFS$$

$$T_s = tDATA_{slowest} + tSIFS + tACK + tDIFS \quad (4)$$

where T denotes the time interval measured to estimate the expected length of a slot-time. P_{idle} is the idle probability defined as idle ratio during time interval T. P_{tr} is the probability that there is at least one transmission during the considered slot time, P_c denotes conditional collision probability, meaning that the probability of a collision seen by a packet being transmitted on the channel. P_c has the same meaning as *p* that will be mentioned next. $1-P_c$ is the probability that transmission occurring on the channel is successful, and is given by the probability that exactly one station transmits on the channel, conditioned on the fact that at least one station transmits. σ is the duration of an empty slot-time, T_s is the average time the channel is sensed busy because of a successful transmission, and T_c is the average time the channel is sensed busy by each station during a collision. T_s and T_c are determined by the slowest station already associated with AP i. Accordingly, estimating P_{idle} plays a key role in knowing *E[slot time]*. We assume the channel state seen by each station in BSS is same, and then P_{idle} of all stations in BSS is same, so each AP can estimate P_{idle} of its own BSS by measuring the channel conditions.

Therefore, the average time required for a client k to transmit a data frame successfully to AP i is given by:

$$\overline{T_{k,i}} = (1-p) \cdot T_{k,i}(0) + \sum_{j=1}^{\gamma} (1-p) \cdot p^j \cdot \left[T_{k,i}(j) + \sum_{m=0}^{j-1} T_{fail}(m)\right] \quad (5)$$

where γ is the Retry limit. In case of two-hand shaking, RetryLimit (LongRetryLimit) is 4 as shown in [1]; *p* is the average up-link transmission failure probability of each BSS, the derivation of *p* is shown in next sub-section. $T_{fail}(m)$ is the time duration corresponding to m^{th} transmission attempt's failure and is given by:

$$T_{fail}(m) = tbackoff(m) + tDATA + tEIFS \quad (6)$$

But above (5) does not consider rate-anomaly: if a newly arrived client selects an AP dealing with clients that use a lower data rate than the newly arrived client's data rate, the expected throughput of the newly arrived client is down-equalized to that of the slowest client, and not to the value derived from (5). We exploit AP's goodput during a constant interval (5 sec) to consider rate-anomaly. Let S be the goodput during the constant interval. On long term, the throughput per client in BSS_i is given by:

$$S = \frac{S_i}{N_i} \cong [\text{throughput per client in BSS}_i] \qquad (7)$$

where S_i denotes AP i's goodput and N_i denotes the number of active clients associated with AP i.

Therefore, the expected throughput of the client is given by:

$$\text{expected throughput}(\theta_{k,i}) = \min(S, \frac{1}{T_{k,i}}) \qquad (8)$$

C. 802.11 Feedback to Infer Average Transmission Failure Probability

We exploit a novel technique to estimate the average up-link transmission failure probability which is related to the number of active clients implicitly, by measuring frequency of retransmission as shown in [15]. Fig. 1 shows the format of a general IEEE 802.11 MAC layer frame. Retry field in 802.11 MAC header is a single bit in length and is used to indicate whether a data or a management frame is being transmitted for the first time or it is a retransmission [1].

When this field is set to 0, the frame is being sent for the first time, when this field is set to 1, the frame is a retransmission of an earlier unsuccessful transmission. A receiver uses this indication to aid in the process of eliminating duplicate frames.

The Retry field can be used as a channel feedback to infer channel conditions, because there is a correlation between p and pattern of Retry values of arriving frames as shown in [15].

As the channel gets more congested, the number of retransmissions increases [1]. By exploiting this indication, a receiver can estimate p in each BSS. i.e., during measure time interval [0, T], if the number of Retry field set to "1" is increasing, it infers that the transmission attempts more often fail due to collisions within BSS as well as with adjacent BSSs' transmissions.

In order to model and analyse the pattern of Retry field, we reuse Bianchi's Markov chain model [15], [16]. More details can be found in [15]. As explained briefly, Fig. 2 shows a discrete-time Markov-chain model describing the back-off window scheme of 802.11 DCF. *b(t)* denotes the stochastic process representing the backoff window size for a given station at time *t*, and *s(t)* denotes the stochastic process representing the backoff stage for a given station at time *t*, where *m* represents the maximum backoff stage. The two-dimensional process *s(t), b(t)* is represented by state $\{s(t) = i, b(t) = k\}$ at time t; as $t \to \infty$, the stationary distribution of the chain is given by:

$$b_{i,k} = \lim_{t\to\infty} P(s(t)=i, b(t)=k), \quad i \in (0,m), k \in (0, W_i - 1) \qquad (9)$$

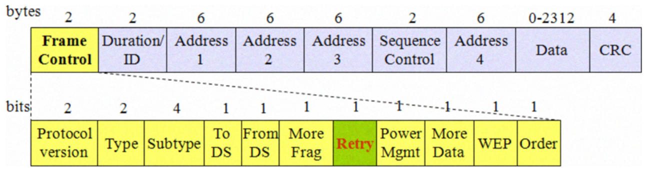

Figure 1. General IEEE 802.11 MAC layer frame format

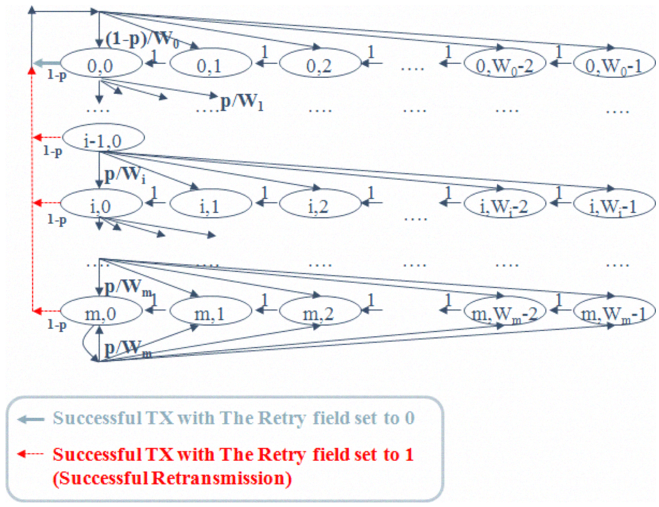

Figure 2. Markov chain model for 802.11 DCF BEB

A transmission occurs when the backoff time counter is equal to zero: a transition from state $\{i, 0\}$ in the chain represents a frame transmission. The Retry field is set to 0 for the transmission at the backoff stage 0; the Retry field is set to 1 for the transmission at other stages.

Hence, we calculate the probability of successful transmission at the first attempt as follows:

$$\frac{C_0}{C_0 + C_1} = \frac{(1-p)b_{0,0}}{(1-p)b_{0,0} + (1-p)\sum_{k=0}^{m} p^k} = \frac{1-p}{1-p^{m+1}}$$

$$p^m + p^{m-1} + \ldots + p^2 + p = \frac{C_1}{C_0} \qquad (10)$$

where the number of Retry field which is set is referred to *i* (*i*=0, 1), and the *C1/C0* denotes the RetryRaio; *m* is the maximum number of backoff stage; the value of *m* is 4 in case of two hand-shaking in WLANs as shown in [1].

D. Implementation Issues

In this sub-section, we will discuss implementation issues related to our proposed scheme, i.e. the modifications required when applying our proposed scheme to current deployed WLANs.

Our proposal needs a client to estimate p of each BSS, after carrying out passive or active scanning. However, a newly arrived client cannot derive exactly p due to hidden nodes; if an AP periodically broadcasts beacon or conditionally sends probe response frames including the RetryRatio related to p directly, each client can derive exactly p of each BSS by overhearing the beacon/probe response frames. The RetryRatio is a good indicator to select the best AP, since RetryRatio reflects the traffic tendency which has been experienced for the last 5 sec. Obviously, this field is only a few bytes long, so it does not result in significant overhead.

In addition, if an AP periodically broadcasts beacon or conditionally sends probe response frames including P_{idle}, each client can derive the *E[slot time]* of each BSS by overhearing to the beacon/probe response frame. The length of this field is only a few bytes too, so it does not result in significant overhead, either.

Finally, we propose a re-association procedure reflecting traffic dynamics. Each client first independently selects an appropriate AP according to the scheme previously described when joining in WLANs. The AP selected may then become a poor choice, since the number of clients accommodated by each AP can change due to new clients' arrivals, and because client traffic pattern is irregular. Then we propose Dynamic AP selection[1] to cope with the various changes in WLANs: if the ΔRetryRatio which a client receives piggybacked in the beacon frame is more than 0.3, each client processes re-scanning and find a proper AP.

IV. PERFORMANCE EVALUATION

In this section, we demonstrate the effectiveness of our proposed scheme compared to existing approaches through ns-2 simulation [17].

A. Simulation Setup

We have enhanced 802.11 DCF mode in ns-2 simulator (ver. 2.33) to support our proposed scheme by modifying the beacon and probe response frame. We simulate the IEEE 802.11b PHY. Carrier sensing range is set to 550m. The transmission rate of each station depends only on the distance between a client and a target AP, and the correlation between transmission rate and distance refers to the ORiNOCO 11b Card Specification [18]. Path loss of radio signals is modelled by the TwoRayground model of ns-2. We assume that all clients and APs use the same transmission power.

We have simulated a multi-cell network that consists of 9 APs operating on the same channel, and all clients are randomly distributed under the coverage of at least 1 AP. We have chosen this scenario to demonstrate the proposed scheme effectiveness under adjacent BSSs' transmission conditions. We use the ARF protocol [19] for rate adaptation in our scenario, and the arrival time of each client is uniformly distributed over a period of 30 sec. And all comparison schemes as well as our proposed scheme perform AP selection without re-association procedure; i.e. Static AP selection.

[1] We define the proposed AP selection without re-association procedure as Static AP selection.

During the simulation, each client generates traffic to its AP; offered traffic is CBR (Constant Bit Rate) UDP traffic, and the packet size is 1000 bytes. We also assume that all clients in the system always have some pending messages for the AP.

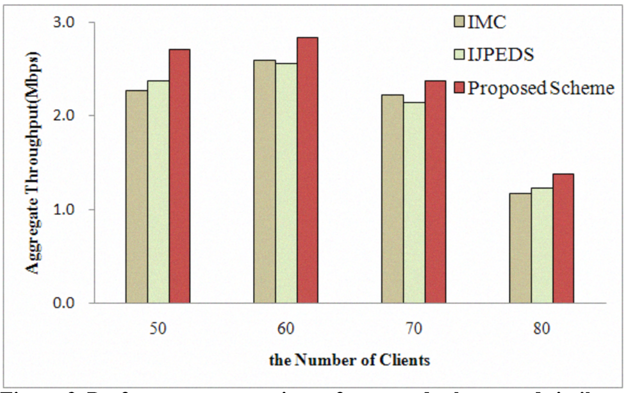

Figure 3. **Performance comparison of proposed scheme and similar existing approach**

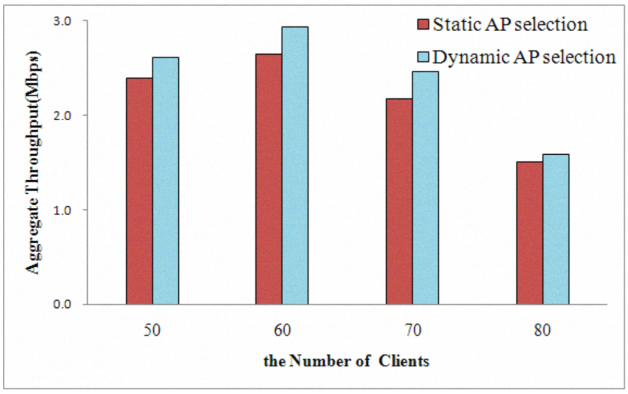

Figure 4. Performance comparison of Static AP selection and Dynamic AP selection discussed in this paper

We have carried out simulation of experiments for 100 sec, actually going a time interval of 68 sec from 32 to 100 sec to calculate the aggregated throughput. At first, we compare the performance of our proposed scheme to similar approaches in [12], [14]. To simulate the approaches in [12], [14], we use the empirical BER (Bit Error Rate) vs. SNR (Signal-to-Noise Ratio) curves provided by Intersil to estimate the FER (Frame Error Rate) [20]. Next, we demonstrate effectiveness of Dynamic AP selection mechanism as comparing to the performance of Static and Dynamic AP selection mechanism discussed in this paper. We conducted simulations under the previously mentioned conditions, except that clients employed Dynamic AP selection. At this simulation, offered traffic is Exponential On/Off UDP traffic to make it dynamic. All results are averaged over 10 runs.

B. Simulation Result

Fig. 3 presents the aggregated throughput of the proposed scheme and existing approaches, when the number of clients is varying from 50 to 80. While the number of clients is increasing, the aggregated throughput of all schemes grows linearly until it reaches the saturation point at which aggregated throughput stops increasing; after that point, the aggregated throughput is decreasing sharply though the number of clients is increasing. It is clear that our proposed scheme can achieve higher aggregated throughput than other approaches; we observe that the proposed scheme performs about 11.7% better than [12] and 12.5% better than [14] respectively. The performance obtained in [12] is less than our scheme's performance, since this approach does not reflect adjacent BSSs' transmission. The performance obtained in [14] is less than our scheme's performance since the measurement value of ATD directly related to the number of active clients has large variations; this factor influences the expected throughput, resulting in wrong AP selection.

Fig. 4 presents the aggregated throughput of Static and Dynamic AP selection mechanism discussed in this paper when the number of clients is varying from 50 to 80. While the number of clients is increasing, the aggregated throughput of all mechanisms grows linearly until it reaches the saturation point at which aggregated throughput stops increasing, and starts decreasing sharply though the number of clients is increasing. Dynamic AP selection mechanism achieves higher aggregated throughput than Static AP selection mechanism; we observe that the former mechanism outperforms about 9.2% than the latter mechanism. Dynamic AP selection mechanism seems to provide a performance improvement as each client is conducting re-association procedure according to traffic dynamic.

V. Conclusions

In this paper, we have proposed a novel traffic-aware AP selection for multi-rate in WLANs. Unlike previous approaches, we consider multiple transmission rates as well as adjacent BSSs' transmission, by estimating more accurately and less intrusively: by exploiting the Retry field in the MAC header, we estimate the transmission failure probability which is related to the number of active clients in each BSS implicitly. We also compared the proposed scheme to the existing approaches. Through ns-2 simulation, we have shown that the proposed scheme yields the highest performance enhancement compared to previous work.

As future work, we plan to extend the proposed scheme to Wireless Mesh Networks (WMN).

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References

[1] IEEE 802.11-2007, part 11 : Wireless LAN Medium Access Control(MAC) and Physical Layer (PHY) specifications, IEEE std. 802.11, 2007

[2] G. Bianchi, S. Choi, "IEEE 802.11 Ad-Hoc Networks," a chapter in Wireless Ad hoc and Sensor Networks, Ahmed M. Safwat (Ed.), Kluwer, to be published in 2004

[3] M. Heousse et.al, "Performance anomaly of 802.11b," in proc IEEE INFOCOM 2003, pp. 836-843, Mar. 2003

[4] H. Lee, S. Kim, O. Lee, S. Choi, and S. Lee, "Available Bandwidth-based Association in IEEE 802.11 Wireless LANs," in proc ACM MSWiM 2008, pp. 132-139, Oct. 2008

[5] A. Nicholson, Y. Chawathe, M. Chen, B. Noble and D. Wetherall, "Improved access point selection," in proc ACM Mobisys, pp. 233 - 245, June 2006

[6] L. Yen, T. Yeh, "SNMP-Based Approach to Load Distribution in IEEE 802.11 Networks," in proc IEEE VTC 2006-Spring, pp. 1196-1200, May 2006

[7] G. Athanasiou, T. Korakis, O. Ercetin, and L. Tassiulas, "Dynamic Cross-Layer Association in 802.11-based Mesh Network," in proc IEEE INFOCOM 2007, pp 2090-2098, May 2007

[8] Y. Fukuda, Y. Oie, "Decentralized Access Point Selection Architecture for Wireless LANs," IEICE Trans. Commun., vol.E90-B, no 9, pp.2513-2523, Sep. 2007

[9] L. Du, Y. Bai, and L. Chen, "Access Point Selection Strategy for Large-Scale Wireless Local Area Networks," in proc IEEE WCNC 2007, pp. 2161-2166, Mar 2008

[10] J. Chen, T. Chen, T. Zhang, and V. Berg, "Effective AP Selection and Load Balancing in IEEE 802.11 Wireless LANs," in proc IEEE GLOBECOM 2006, pp. 1-6, Nov 2006

[11] S. Vasudevan, K. Papagiannaki, C. Diot, J. Kurose, and D. Towsley, "Facilitating Access Point Selection in IEEE 802.11 Wireless Networks," in proc ACM Sigcomm IMC, pp. 26-26, Oct 2005

[12] M. Abusubaih, S. Wiethoelter, J. Gross, and A. Wolisz, "A new access point selection policy for multi-rate IEEE 802.11 WLANs," International Journal of Parallel, Emergent and Distributed Systems, vol. 23, no. 4, pp. 291-307, Aug. 2008

[13] H. Gong, J. Kim, "Dynamic Load Balancing through Association Control of Mobile Users in WiFi Networks," IEEE Trans. of Consumer Electronics, vol. 54, no. 2, pp. 342-348 , May. 2008

[14] K. Sundaresan, K. Papagiannaki, "The need for cross-layer information in access point selection algorithms," in proc ACM Sigcomm IMC, pp. 257-262, Oct. 2006

[15] J. Choi, J. Na, Y. Lim, K. Park, and C. Kim , "Collision-aware Design of Rate Adaptation for Multi-Rate 802.11 WLANs," IEEE J. Select. Areas Commun, vol. 26 , no. 8, pp. 1366-1375, Oct. 2008

[16] G. Bianchi, "Performace Analysis of the IEEE 802.11 Distributed Coordination Function," IEEE J. Select. Areas Commun, vol. 18, no. 3, pp. 535-547, Mar. 2000

[17] The Network Simulator ns-2. http://www.isi.edu/nsnam/ns/

[18] Orinoco 11b Client PC Card Specifications http://www.proxim.com/learn/library/datasheets/ 11bpccard.pdf

[19] Ad Kamerman and Leo Monteban, "WaveLAN-II: a high-performance Wireless LAN for the Unlicensed Band," Bell Labs Technical Journal, vol.2, no.3, pp.118-133, Aug. 1997

[20] Intersil, "HFA3861B; Direct Sequence Spread Spectrum Baseband Processor.", Jan. 2000