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Access Point Selection Strategy for Large-scale Wireless Local Area Networks

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Abstract – **This paper presents an Access Point (AP) selection strategy for the (re)association procedure in large-scale WLAN. The proposal considers the difference of node topology among candidate Basic Service Sets (BSSs), wherein the effects from hidden terminals are emphasized due to its significant impact on throughput degradation. Comparing with existing mechanisms, the proposal combats load imbalance problem that the popular signal strength measurement based selection strategy may cause. Meanwhile, it estimates the BSS load status in more accurate way by differentiating hidden terminal from others, so a higher throughput is resulted. More significantly, the proposal uses the advertised information of the Beacon/Probe Response frame in IEEE802.11e, without any hardware modification. Such back-compatibility facilitates the implementation over currently deployed WLAN. The performance is validated via simulation which shows that the proposal can achieve up to 20% throughput enhancement over existing methods particularly over the uplink.**

I. INTRODUCTION

Driven by increasing demands for internet access, the wireless local area network (WLAN) has been widely configured in large scale, by use of a set of access points (APs) connecting to the Ethernet backbone. The serving areas of APs, named basic service sets (BSSs) in IEEE 802.11, are always overlapped for the seamless coverage and capacity enhancement [1]. Then a station within the overlapped area shall select one AP according to some criterion to establish association for the subsequent data delivery.

Fig. 1 presents a simple scenario comprising two BSSs. A station (STA) is located in the overlapped area and may detect signals from both AP1 and AP2. Since IEEE 802.11 bases on a contention based medium access control (MAC) protocol, the selection result of the STA shall have a great effect on the BSS performance. Therefore, the AP selection strategy, which is going to be discussed in this paper, becomes quite important for the large-scale WLAN.

In this paper, we approach the AP selection by taking into account the hidden terminal problem which has not been done in prior arts. As a hidden terminal may cause much severer throughput degradation comparing with non-hidden STA [7], it is preferable to differentiate them before joining the BSS, which hence elicits our proposed method.

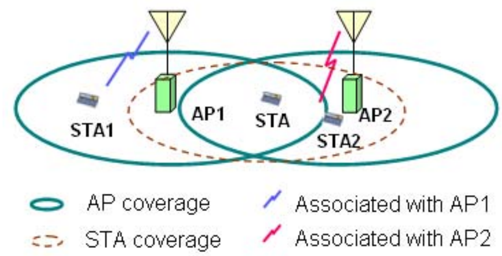


Fig. 1 scenario for AP selection in overlapping BSSs

The rest of the paper is organized as follows. We brief the related work in section II and overview the channel scanning process of IEEE 802.11 [10] supporting AP selection in section III. The proposed strategy is then described and discussed in view of implementation in section IV. Performance evaluation is followed in section V. The paper is finally concluded in section VI.

II. RELATED WORK

The conventional approach to AP selection is based on the received signal strength (RSS) measurements from candidate APs. By associating with the AP promising a better channel condition, it serves stations (STAs) more reliably and is likely to support more sessions due to its preference to higher data rates [2]. However, as system load is often unevenly distributed over operational WLAN [3-4], the scheme may cause traffic aggregation within a few of BSSs hence leading to congestion and performance degradation.

Such load imbalance is being studied by directing some STAs to adjacent light-loaded BSSs during AP selection. The authors in [5] suggest a method by considering the state information including the number of STAs and traffic amount at APs. An association algorithm which estimates the direction of a mobile terminal' movement besides the load level is also presented in [6]. They could both alleviate the load congestion, but the metrics representing load level do not reflect the actual BSS status, as the hidden terminal may cause severer performance degradation than a STA within the sensing range [7]. Some predictive schemes are then proposed for more accurate load estimation in respective BSSs. Reference [8] describes the methodology by estimating the potential bandwidth based on the delays experienced by beacon frames. However, it assumes a same access priority between beacons

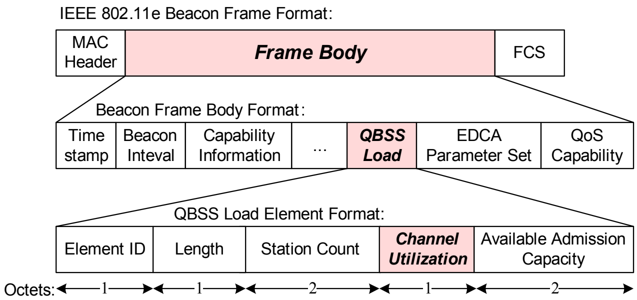


Fig.2 Beacon Frame Format in IEEE 802.11e

and other frames, which is inconsistent with IEEE 802.11. The bi-directional link rate is further considered in [9], but it is restricted to point coordination function, not applicable to the popular WLAN products using the distributed coordination function (DCF). Therefore, an AP selection strategy being aware of hidden terminal effects and well basing on the IEEE 802.11 is desired.

III. Channel Scanning in IEEE 802.11

Before a STA could be associated with an AP and start data transmission, channel scanning is performed to acquire some necessary information for AP selection. IEEE 802.11 defines two scanning modes, passive and active scanning, prior to the association or reassociation process (see Fig. 3).

In passive mode, an AP periodically broadcasts the beacon frames including the BSS-specific information. A STA listens to each candidate channel and scans for the beacon matching the desired identity. The load status contained in beacons can be used for determining the BSS the STA is to join. Fig.2 shows the beacon frame format defined in IEEE 802.11e [11]. Wherein, a QBSS (QoS BSS) Load element is optionally present to indicate the current STA population and traffic levels in the infrastructure QBSS. Specifically, the *Channel Utilization* element, which is defined as the percentage of time the QAP (QoS AP) sensed the medium busy, will be used in the proposed AP selection strategy (to be discussed later). Apart from the passive scanning mode, a STA may also actively scan the channel by sending a probe request frame containing the desired identity. The AP, upon receiving a probe request frame matching its own identity, responds with a probe response frame, which also contains the QBSS Load element as illustrated in Fig.2.

When all the candidate channels have been scanned using either mode, the STA could gather the load status of respective BSSs and hence select an AP to associate with.

In consistent with above scanning process, we design an AP selection strategy by using the QBSS Load information to estimate the *potential hidden terminal (HT) effect*. In this way, a STA is likely to join the BSS where less contention with HTs is expected. Also the negative impact on existing STAs due to this newly associated STA can be minimized to promise a higher throughput. Moreover, the proposal can be achieved by simple channel sensing, which has a good compatibility with IEEE 802.11e and facilitates the implementation over currently deployed WLAN.

IV. Proposed AP Selection Strategy

In this section an AP selection scheme being aware of the hidden terminal effect is described in the IEEE 802.11 based WLAN. We first define the *potential hidden terminal effect* which is the basis for selection. The AP which corresponds to the minimum potential HT effect shall be selected. Then the operation steps are detailed taking the passive scanning as example. Finally the implementation issues are discussed.

A. Potential Hidden Terminal(HT) Effect

We estimate the potential HT effect f_i in each candidate BSS i as shown in equation (1). f_i is a quantified metric for evaluating the extent how much a STA is to be affected by joining this BSS, wherein i denotes the channel index in the candidate channel list V ($i \in V$) of the STA to be accessed.

$$f_i = (u_i - r_i) \cdot L / v_i \qquad (1)$$

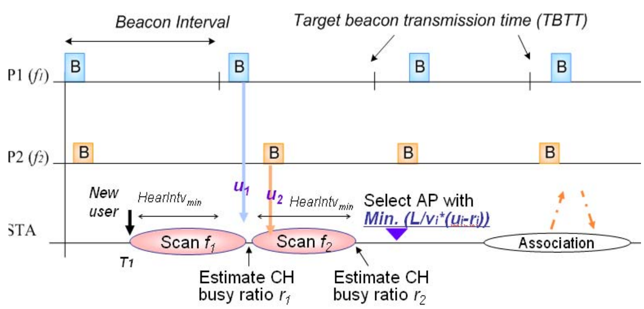
The idea of HT estimation in this paper comes from the fact that HTs' transmission could not be heard. We define u_i as the average channel utilization, i.e. the percentage of time that the channel is occupied in the BSS i. r_i is used to express the channel busy ratio that the studied STA could hear the medium busy. So we may have $(u_i\text{-}r_i)$ to denote the channel usage that the STA could not hear even the channel is still in busy. Since such channel occupation is caused by the HTs, we may approximate the value of $(u_i\text{-}r_i)$ as one of the factors that determines the potential HT effect in BSS i. The larger it is, the heavier HT effect there will be.

Besides, the potential HT effect the studied STA is going to suffer also depends on the time interval during which the frame collisions is likely to occur. Given the basic access protocol, the time required to transmit the data frame shall decide the collision window. That is, a shorter data transmission time corresponds to lower collision possibility with HTs. Therefore, by estimating the maximum supportable data rate v_i via RSS measurement, we could obtain the data transmission time as L/v_i, wherein L is the average data length to be sent by the studied STA. By combining these two factors, the potential effect from HTs when accessing AP i could then be resulted.

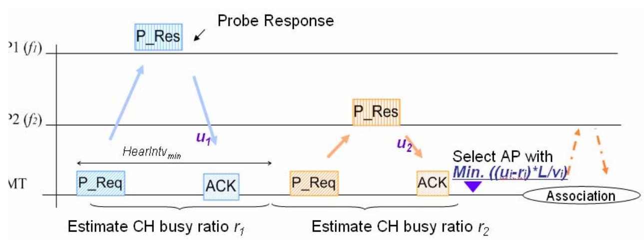
Taking an overview of the potential HT effect in (1), it not only preserves the benefit of RSS measurement by preferring a higher data rate, but also balances the load via averaging the impacts from HTs in respective BSSs. The proposed selection strategy is expected to achieve better performance as compared with existing methods.

B. Operation steps

Based on aforementioned scanning process, the proposed method operates as described in Fig.3. The scenario shown in Fig.1 is exampled here for simplicity, wherein two BSSs are



(a) At passive scanning mode



(b) At active scanning mode

Fig. 3 Operation steps of the proposed AP selection method

working on the channels f_1, f_2 without co-channel interference. It is reasonable as three non-overlapping channels are supported in IEEE 802.11b and eleven are supported in IEEE 802.11a.

Fig.3(a) shows the operation steps in time axes at passive scanning mode. Each AP periodically schedules the beacon frames (the "B" block in Fig.3) at a series of target beacon transmission times (TBTTs) separated by a fixed beacon interval. If the medium is determined to be busy, the AP shall defer the actual beacon transmission according to the basic access mechanism.

A STA, after entering WLAN, starts scanning channels in its candidate channel list $V = \{f_1, f_2\}$. Not until a beacon frame is successfully received over the currently scanned channel, e.g. f_1, the STA extracts the *channel utilization* field as highlighted in Fig.2, and records the value as u_i. Meanwhile, it estimates the maximum supportable data rate in the BSS i as v_i via RSS measurement of the received beacon. Given that the data frame to be transmitted is L-bit in length, the expected data transmission time when this AP i is selected could be formulated as L/v_i.

Immediately after such beacon processing, the STA further determines whether the elapsed time since scanning this channel has exceeded the predefined minimum required hearing interval $HearIntv_{min}$. If the condition is not satisfied, such as upon receiving beacon from AP2, the STA shall continue hearing the channel until the threshold is reached. Otherwise, the STA calculates the percentage of time that it heard the channel busy during the elapsed scanning period T_s and counts it as v_i.

It is possible that the STA could not detect anything useful during scanning a channel. It may be caused by insufficient link quality to recognize a beacon, or due to the unavailability of the desired identity. In IEEE 802.11 a maximum scanning period *MaxChannelTime* is defined. A STA shall consider the channel as unusable and remove it from the candidate channel list if no beacon frames are successfully detected during *MaxChannelTime*.

After the STA has scanned all the channels in above way, it could keep a table containing a set of values $<u_i, v_i, r_i>$ for all candidate channels. Then the STA calculates the potential HT effect f_i in respective BSSs according to equation (1). The AP corresponding to the minimum value of f_i is to be selected.

Similarly, the operation flow using active scanning is shown in Fig.3 (b). The difference between them is that the *channel utilization* value u_i is obtained by reading the probe response (P_Res) frame instead of the beacon. Since other steps are exactly the same as in passive mode, it is not to be detailed due to the space limitation.

C. Implementation Issues

In this subsection, we are going to discuss the issues related to implementation, i.e. the modifications required on software/hardware when applying this proposal to current deployed WLAN. The less modification shall be preferred for its better compatibility with existing systems.

To enable the proposed method, a STA need acquire $<u_i, v_i, r_i>$ after channel scanning. u_i is exactly defined in IEEE 802.11e as the value of *channel utilization* field, which is contained in the beacon or probe response frame sent from APs. v_i is estimated based on the legacy RSS measurement over the air interface. r_i can be counted by a STA using the clear channel assessment (CCA). In this sense, the proposal can be easily implemented via only software modification.

In addition, the parameter $HearIntv_{min}$ defined in the proposal needs to be specified in implementation. $HearIntv_{min}$ is used for estimate r_i. If a larger value is used, the heard channel busy period would more accurately reflect the ratio of non-HTs, but a longer scanning period may be resulted causing channel waste. Therefore, the $HearIntv_{min}$ setting should be a tradeoff, which may be adjustable based on the beacon interval, channel load and traffic type, etc. For simplicity a moderate value could be set independent of the varied channel conditions.

V. Performance Evaluation

In order to evaluate the performance of the proposed AP selection strategy we run the computer simulation on an IEEE 802.11 based platform using Matlab. The scenario shown in Fig.1 is adopted, wherein co-channel interference is ignored between the two BSSs.

A. Channel and traffic model

We model the BSS coverage as a circle while assuming that the signals only experience path loss (PL) during wireless propagation, i.e. log-normal shading effect and fast fading are ignored. PL is considered to be proportional to the exponential of the STA-AP distance d. Let D_{max} denote the maximum transmission range at the basic data rate v_1 = 5.5Mbps,

Table I. Simulation parameters

Parameters	Values
Maximum transmission range (D_{max})	100 m
Distance between APs	40 m
Available Data transmission rate (v_k, k = 1~2)	[5.5, 11] Mbits/s
Required Receiver Threshold [12] (P_{thr_k})	[-79, -75] dBm
Path loss ratio (n)	3
Beacon Interval	100 ms
MaxChannelTime	100 ms
HearIntv$_{min}$	50 ms
CWmin/CWmax (VoIP)	7/15
CWmin/CWmax (BE)	31/1023
Retry Count (VoIP/BE)	3/7

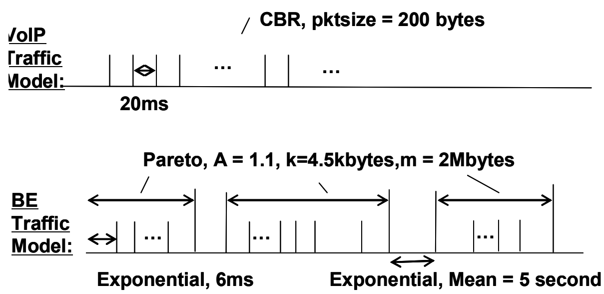


Fig. 4 VoIP and BE traffic models adopted in simulation

we could have

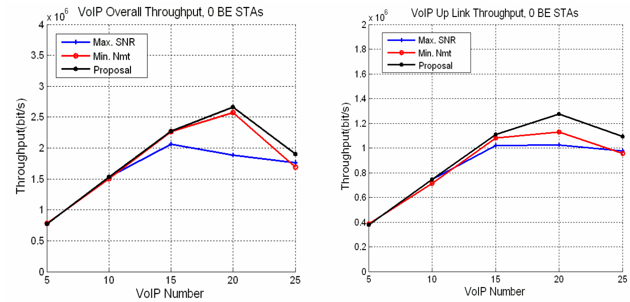
$$P_{thr\_v_1} = P_t - PL(D_{\max}) \qquad (2)$$

Then the relationship between the transmission range D_k for higher data rate v_k and D_{max} can be expressed as

$$P_{thr\_v_k} - P_{thr\_v_1} = 10n \cdot \log(D_{\max} / D_k) \qquad (3)$$

wherein P_{thr_vk} denotes the required power level at the receiver for decoding the data frame transmitted at v_k; n is the path loss ratio, as listed in Table I. The STAs located within the range of D_k can thus be allowed a maximum data transmission rate v_k.

As for the traffic, the best effort (BE) service in terms of web browsing and constant bit rate (CBR) type VoIP service are assumed in the simulation. A VoIP data payload, 200-bits in length, is capsulated into a MAC Payload Data Unit (MPDU) and sent over the MAC layer according to the basic access mechanism in IEEE 802.11. The VoIP frame shall be dropped after staying in the buffer for longer than 200 ms. For the BE traffic, the Pareto-model is adopted as shown in Fig. 4. The data payload packet of variable length is then divided or padded into multiple MPDUs. Each data frame is 1500-bits long and is dropped when it failed after seven-time retransmission. The parameters for the traffic model are listed in Figure 4. Furthermore, the STAs are assumed unevenly distributed in the scenario, where BSS1 monitored by AP1 is more heavily loaded than the other. Due to the randomness arising from STA distribution, we ran the simulation several times and gathered the average value after a given number of STAs have joined the system for ten seconds.



(a) Total throughput (b) Uplink throughput

Fig. 5 Throughput performance in case of only VoIP STAs

B. Evaluation Metrics

The performance of the proposed AP selection scheme is compared with that based on the RSS measurement and STA count. Given the distance related channel model, the RSS is approximated to the detected SNR, i.e. the AP which provides the *max. SNR* is selected. Another method is briefed as *Min.* N_{mt}, wherein the BSS which has a smaller number of STAs is selected for the sake of load balance.

The evaluation metrics include the total throughput in terms of the successfully transmitted data payload bits per second in both BSSs, the uplink throughput, i.e. the successfully delivered data bits per second from STAs to APs, and the packet loss rate which shows the ratio of lost data frames due to collision or dropping to the total number of delivered data frames.

C. Simulation Results in case of VoIP-Only Traffic

Fig. 5 shows the throughput performance in case of only VoIP STAs. As seen from Fig.5, the proposed AP selection method outperforms the other two schemes in both total and uplink throughput. In particular, the uplink performance is significantly improved by over 10% due to efficient collision avoidance with hidden terminals.

According to Fig.5(a), the *Max. SNR* method performs the worst as STAs may gather within one BSS in unbiased traffic distribution case. Therefore the throughput in BSS1 is largely degraded because of the severe frame collision while leaving the BSS2 underutilized. The *Min.*N_{mt} scheme alleviates such load imbalance by equaling the number of STAs in the two BSSs, so that the throughput is greatly increased. Comparing with them, our proposed AP selection method further gains better performance because it takes the hidden terminal effect into account. Especially, with the increase of the number of STAs, i.e. the increase of BSS load, the HT problem becomes severer, so that the proposal works more efficiently and improves the throughput more significantly. For example, the proposal increases the total throughput over *Min.* N_{mt} from 6% to 14% when the number of STAs increments from 20 to 25.

We further plot the uplink throughput in Fig.5 (b). Since the key point of the proposal is to mitigate the frame collision with hidden terminals, the uplink performance shall be greatly enhanced. As expected, the throughput enhancement is much

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more significant comparing with the total throughput. Given 20 STAs, the uplink throughput can be increased by over 10%, validating that it is the collision avoidance over uplink that contributes to performance enhancement.

D. Simulation Results in case of Mixed VoIP&BE Traffic

We also study the performance of VoIP STAs given that ten BE STAs are coexisting in the scenario. The Enhanced Distributed Channel Access (EDCA), which is specified in IEEE 802.11e, is adopted to differentiated the BE access from VoIP STAs. On the downlink, the VoIP packet is transmitted always prior to the BE traffic as long as it is available in the buffer resided at APs. Herein we focus on the performance of VoIP STAs for its stringent QoS requirement and preference over BE STAs. As shown in Figure 6, the VoIP performance is significantly enhanced since the longer BE frames result in a heavier collision from hidden terminals to the VoIP STAs.

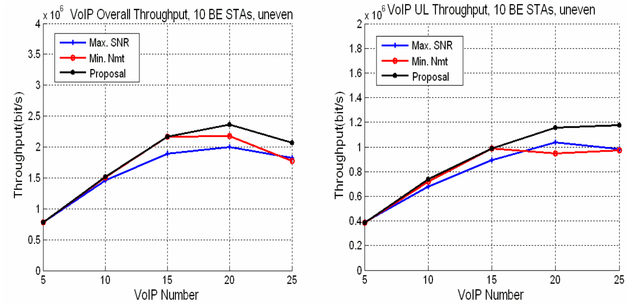
Fig. 6 (a) depicts the total throughput, wherein the proposed AP selection scheme still outperforms the others. Comparing with Fig. 5 (a), the difference between *Max. SNR* and *Min.* N_{mt} is decreased, because *Max. SNR* tends to allow a higher data transmission rate as well as less collision than that using *Min.* $N_{mt.}$ Such benefit is becoming more significantly and can largely compensate the load imbalance effect in case of longer data frame.

As for the proposal, it takes the advantages of *Max. SNR* and *Min.* N_{mt} simultaneously, so that the throughput can be further increased. Especially when BE STAs coexist with VoIP STAs, the longer BE data frame corresponds to a longer potential collision window and a severer effect from hidden terminals. Therefore, the total throughput could be more greatly increased by over 10% given 10 VoIP STAs, in comparison to the 6% in Fig.5 (a). Similar with what has been explained in Fig. 5, the throughput gain can be further expanded with the increase of channel load. The tendency still comes from the severer hidden terminal effect because of the contention of larger number of stations.

Fig. 6 (b) shows the uplink throughput of VoIP STAs. Especially, the proposed method enhances the performance by up to 20%. In consistence with the essence of the proposal, the hidden terminal aware scheme shall work more efficiently given heavier hidden terminal problem, which may be related to the frame length and channel load. That is, the performance enhancement would be more significant with the increase of number of VoIP STAs and the increase of data length.

VI. CONCLUSION

In this paper we proposed an efficient AP selection strategy by taking into account the hidden terminal effect. The essence of the proposal is to estimate the potential hidden terminal effect the STA may suffer during channel scanning. Since the hidden terminals could not be heard, we design the function f_k to quantify the effect from hidden terminals, using the public information from APs and local sensed time period. Without increasing any overhead, the proposal is well compatible with



(a) Total throughput (b) Uplink throughput

Fig. 6 Throughput performance in case of Mixed VoIP&BE STAs

current IEEE 802.11e products and easy to be implemented. To evaluate the performance, the proposal is compared with the *Max. SNR* and *Min.* N_{mt} methods in case of uneven traffic distribution. The simulation results show that the proposal outperforms the existing schemes in terms of both total and uplink throughput no matter BE STAs exist or not. In particular, the uplink throughput is greatly improved by up to 20% due to alleviating the frame collisions with hidden terminals via AP selection. Future work will include more simulation work by varying the parameters and the QoS is to be further considered during AP selection.

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