QoS-Aware Load Balancing Scheme in Dense Wi-Fi 6 WLANs

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Abstract. Nowadays, increasing mobile and wireless usage demand accelerates new enhancements on IEEE 802.11 family to provide concurrent transmission and high efficiency. Thus, IEEE 802.11ax is released with the aim to improve overall throughput in dense WLANs considering the overlapping channel interference. However, the current WLANs suffer from uneven load distribution among the Access Points (AP). Because a station simply connects to the AP with the highest received signal strength indication (RSSI) in a legacy association way. And RSSI might not be the only criteria in the current WLANs due to the variety of application requirements and high date rates. Therefore, we propose a complete association scheme called Access Controller (AC) to manage admission, association, and adaptive carrier sensitivity control as a whole. The station from an overloaded AP is handed to a less loaded AP by considering various crucial metrics such as packet delivery ratio, fairness, RSSI, throughput, and round trip time. After effective load balancing, we adaptively tune the carrier sensitivity threshold to enhance concurrent transmission in IEEE 802.11ax WLANs. The results show that the proposed AC scheme outperforms in terms of fairness and per-station throughput in dense WiFi6 scenarios with over 500 stations.

Keywords: IEEE 802.11ax · Dense WLANs · QoS · Load balancing

1 Introduction

The IEEE 802.11ax task group has been newly realized the new promising amendment for High Efficiency (HE) Wireless Local Area Networks (WLANs) in 2020. One of the leading features of 802.11ax is Special Reuse (SR), which aims at improving throughput in dense scenarios with a high volume of access points (APs) and increased number of stations (STAs) per AP. The escalating necessity of dense AP deployment leads up Overlapping Basic Service Set (OBSS), where STAs can connect more than one AP with mostly similar signal strength. However, the current 802.11 standards give the responsibility of selecting an AP to the STAs. A STA simply selects an AP according to the strongest Received

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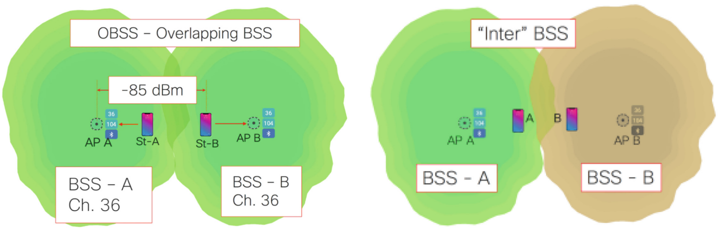
Signal Strenght Indicator (RSSI). However, the highest RSSI is not necessarily to be the best choice because the load of APs varies with BSS traffic flow and many other factors. The current unqualified AP selection mechanism causes an imbalance load among APs, fairness issues between STAs, and inefficient usage of resources. Despite RSSI being an essential criterion for selecting AP, divergent traffics, and data rate requirements of different applications imply the new definition of AP selection. Such a new definition should be supported with adaptive carrier sensitivity threshold (CST) because co-channel interference makes it challenging to balance STAs among APs [1].



(a) OBSS in legacy WiFi

(b) OBSS in WiFi with BSS coloring

Fig. 1. Before and after BSS coloring is enabled [2]

Thanks to the new 802.11 amendment, namely WiFi6 (or formally IEEE 802.11ax), the term SR reveals BSS coloring implementation in WLANs. BSS color is 6 bits length data placed in frame preamble to determine the owner BSS of the frame without decoding the entire frame. The sensing frame with the same color means intra-BSS transmission; different color shows inter-BSS transmission. By recognizing the owner of the inter-BSS frame, concurrent intra-BSS transmission can continue. As seen in Fig. 1b, STA-A and STA-B are connected to different APs, naming AP-A and AP-B, respectively. However, both STAs are placed near the cell-edge of AP's ranges, and they sense their frames in case of concurrent transmission without BSS coloring. This was one of the challenging operations in legacy dense WLANs. On the other hand, when two BSS have different BSS colors, then STA-A and STA-B simply ignore each other's frame because they know their signals never be collied. Besides, BSS coloring enhancement enables STAs to adaptively tune CST by distinguishing OBSS packets with corresponding colors.

In dense deployment WLANs before the BSS coloring scheme, studies only propose STA-AP load balancing schemes without deploying adaptive CST. The problems mentioned above and BSS coloring enhancement motivate a new definition of load balancing mechanism in dense 802.11ax WLANs. Such a new definition of load balancing come with three research questions as follows: (i) how to integrate BSS coloring enhancement to deal with interference issue of OBSS, (ii) which STAs should be switched and how to select target AP, (iii) what criteria will be used to define the load of BSS. To point out these research questions, we propose a QoS-aware load balancing scheme runs in a centralized controller called Access Controller (AC) to increase concurrent transmissions and the efficiency of 802.11ax WLANs. The AC entity operates a load balancing mechanism enhanced with adaptive CST to adjust carrier sensing range dynamically. Then AC uses the global view of WLAN and takes network information from APs to select candidate STAs and re-associate to the target AP. Finally, the framework extensively defines the load for WiFi6 WLANs, considering various application requirements.

The rest of the paper gives the related works on AP selection, and load balancing in WLANs, then presents our contributions in Sect. 2. After that, the network model is presented in Sect. 3, and the proposed framework is introduced in Sect. 4. Moreover, the simulation parameters and evaluation results are discussed in Sect. 5. Finally, the summary of the proposed scheme is concluded in Sect. 6.

2 Literature Review

Different management operations are studied in IEEE 802.11 WLANs and one of the promising areas is to provide an enhanced association mechanism supported with adaptive CST. Many studies discuss association mechanisms for load balancing and adaptive CST separately. And few studies focus on both of them as a whole. Moreover, current studies propose various AP-STA association methods in place of the legacy strongest RSSI-based scheme. In that point, the proposed schemes are examined in two groups: centralized and STA-driven approaches.

The most practical STA-driven approach is the legacy strongest RSSI-based method which is also used in IEEE 802.11 WLANs. Within the STA-driven approaches, other studies use different metrics rather than RSSI. STAs can estimate the available bandwidth before the association procedure [3]. Or another study leverages interference of overlapping WLANs to select the most appropriate AP [1]. Kim et al. propose a scheme to measure the interference using external devices to find an AP with the least interference level [4]. Without deploying a centralized controller might accelerate the deployment time and decrease communication overhead. But STA-driven methods are lack global view information by nature.

Therefore, a centralized approach is another straightforward way to design an association mechanism. The centralized methods solve the load balancing problem either by managing the association & disassociation process or adjusting coverage area & sensitivity threshold adaptively. Some studies also use both methods in the same time [1].

Tang et al. [5] focus user demands to allocate bandwidth according to the users' requirement. Raschellà et al. [6] proposes a centralized controller based on SDN and considers the QoS requirements of the user's traffic. Gong and Yang [7] study aggregated throughput to balance load among APs in heterogeneous STAs. Peng et al. [8] analyze achievable normalized throughput and channel competition to select AP for association requests. Manzoor et al. [9] uses various metrics to define the load for AP selection and deploys a SDN model to monitor and control the WLAN.

Until now, none of the studies have analyzed load balancing issue in IEEE 802.11ax (or simply WiFi6) WLANs. Since WiFi6 comes with crucial enhancements such as BSS coloring, it should be taken separately in the design step. The studies [10] and [1] simulate the proposed approach in WiFi6 WLANs, but they do not use any specific features of WiFi6, which might help to design an association or adaptive CST mechanism.

Consequently, in order to fill explained gap and to provide a complete association mechanism with the aim of load balancing and fair channel access, we propose a novel Access Controller entity on the top of our design. And AC observes various metrics to run Decision Tree model to select candidate AP. The main contributions of this paper are summarized as follows:

- We propose the Access Controller entity as a centralized controller, which contains admission control, association control and adaptive CST tuning modules to form a complete association mechanism in IEEE 802.11ax WLANs.
- The admission control trains and tests the Decision Tree model with eight different categories to extensively analyze the load of the network.
- We introduce a new parameter, called as candidate strength parameter to select most appropriate STAs to shift between APs.
- Finally, we integrate adaptive CST mechanism with the proposed association procedure to provide fairness after load balancing and to adaptively tune CST for concurrent transmissions.

3 Network Architecture

In this study, we consider densely deployed WLAN scenarios where several APs' coverage areas are overlapped by building Overlapping Basic Service Set (OBSS). In order to model overlapped scenarios and consider orthogonal channels' negative effects [11], all APs are considered to operate in the same channel in 2.4 GHz band. Since using orthogonal channels affects the transmission quality between APs, this study only considers load balancing scheme between APs operates on same channel, not between channels. Moreover, APs are assumed to belong same WLAN service provider, which is the typical characteristic of dense WLANs. It is also worth mentioning that IEEE 802.11 standard supports the seamless roaming among the BSSs [12]. The STAs can be handover freely inside an Extended Service Set, which is a form of multiple BSS deployed by a single service provider in the infrastructure network.

All APs are connected to the centralized Access Controller (AC) through wired connection as seen in Fig. 2. The centralized controller has a global view on WLANs in which load metrics are collected from each AP thanks to *agent*. Collected metrics are then processed in the AC modules, naming *admission control* and *association control* to run proposed load-balancing scheme.

Each BSS has its own unique BSS color assigned by the service provider during WLAN deployment time without any collision. An example BSS coloring assignment is imitated in Fig. 2 by presenting AP's range with different colors.

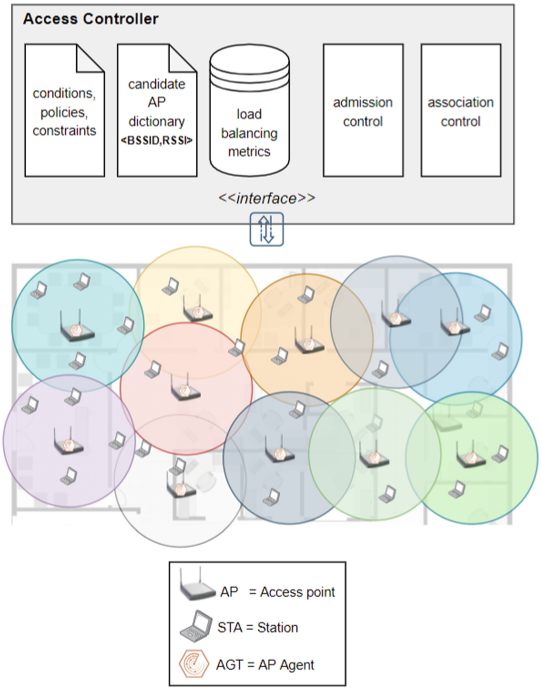


Fig. 2. The proposed load balancing network architecture

3.1 Problem Definition

We consider an ESS that involves k interconnected BSSs and N STAs. Let $\mathcal{B} = \{B_1, B_2, ..., B_k\}$ be the set of BSS in the dense WLAN, each BSS contains one AP, AP_i, where $i = 1, 2, ..., k$ and set of users, $\mathcal{U}_i$, belonging B_i. We assume the number of STAs which are associated with AP_i is $n_i = |\mathcal{U}_i|$, and N is the total number of STAs in WLAN, where $N = \sum_{i=1}^{k} n_i$. Also, it is known that APs have a maximum number of connected STA limit that the device handles whether a STA transmit data or not. Thus c_i^{max} shows the maximum number of STAs that can associate to AP_i. All STAs have a candidate AP list, $\mathcal{C}$, and $\mathcal{C}_j$ shows $j-th$ STA's candidate AP list. That is, STA j is within the coverage areas of APs in $\mathcal{C}_j$. Let $\mathcal{I}$ is the set of intersections of APs in the ESS. All notations used in the paper is listed in Table 1.

Table 1. Notations

Symbol	Explanation
$\mathcal{I} = \{I_1, I_2, ..., I_m\}$	Set of intersections of APs in the ESS
N	Total # of STAs in WLAN
$\mathcal{B} = \{B_1, B_2, ..., B_k\}$	Set of BSS in an ESS
k	# of BSS in an ESS
$\mathcal{B}^i = \{B_r, B_{r+1}, ..., B_{r+p_i}\}$	Set of BSS in intersection I_i
p_i	Number of APs (i.e. BSSs) in intersection I_i
AP_i	AP of i^{th} BSS
$n_i = \|\mathcal{U}_i\|$	The number of STAs associated with AP_i
c_i^{max}	Maximum number of connected STA limit of AP_i
$\mathcal{C}_j$	$j-th$ STA's candidate AP list
$\mathcal{U}_i$	The set of connected STAs in i^{th} BSS
$\mathcal{U}^i$	The set of STAs in i^{th} intersection, I_i
U_j^i	A STA connected to AP_j and placed in the I_i
$\mathcal{M} = \{M_1, M_2, ..., M_m\}$	Set of DT models
$\mathcal{J} = \{J_1, J_2, ..., J_m\}$	Set of Jain's Fairness Index
γ	Candidate strength parameter
T	AC data collection period

4 The Proposed Access Controller Scheme

The Access Controller (AC) is the centralized server to monitor and control the ESS. STAs and their candidate APs list $\mathcal{C}$ are continuously observed, and changes are saved in the dictionary. A candidate AP is 3-tuple data with <*BSSID, RSSI,* γ> values recorded in the list $\mathcal{C}$ for each STA. BSSID is the unique value used in the BSS to assign an ID to each AP in the WLAN. This identifier is called a basic service set identifier (BSSID). The second value is Received Signal Strength Indicator (RSSI), which measures how well STA can hear a signal from an AP. The last value γ is the proposed *candidate strength parameter* to show the strength of candidate AP for STA handover. Note that in this network architecture, all STAs and APs belong to the same ESS, thus they use the same extended basic service set identifier (ESSID). Three main modules of AC, naming Admission Control, Association Control, and Adaptive CST Control as follows.

4.1 Admission Control

The collected metrics are saved in the database of AC as also seen as *load balancing metrics* in Fig. 2. The dataset used as an input in DT algorithm, $X^{N \times F}$ contains N samples, and F features. In our complete DT-based admission control system, each intersection I_i has own DT model trained with APs and STAs placed in the intersection I_i. Let I_i is the $i-th$ intersection where $0 < i < m$. And suppose p_i is the number of APs (i.e. BSSs) in intersection I_i, where $2 < p_i < k$ and k is the number of APs in the ESS. Let U_j^i shows a STA connected to AP_j and placed in the I_i. In the light of these definitions, $M_i \subset \mathcal{M}$ is a DT model belongs to intersection I_i with the p_i APs, and trained with dataset $X_i^{N_i \times F_i}$. The features are basically: (i)RSSI values of p_i APs in the intersection, (ii)J_i, (iii)number of STAs in each p_i APs, (iv)packet delivery ratio (PDR) of p_i APs, (v)bit error rate (BER) of p_i APs, (vi)average loss rate of p_i BSSs, (vii)normalized throughput of p_i BSSs, (viii)average round-trip-time of p_i BSSs, totally $7p_i + 1$ features. These features are as follows:

RSSI - Received Signal Strength Indicator (RSSI) is a measurement of how a STA receives the signal from the AP in the receiver's antenna during the packet transmission. RSSI value strongly depends on the distance. Thus, considering RSSI as the only metric for the AP association and load of BSS is not sufficient. Because usage of RSSI as only metric can not determine the interference on links [13]. Therefore, RSSI metric should be supported with other well-justified load criteria to measure the load of BSS acutely. RSSI value can be learnt from control packets during the association process. The value vary from 0 to $RSSI_{max}$ and the maximum value depends on the wireless card manufacturer. For example, Cisco cards use $RSSI_max = 100$, and they use $RSSI - 95 = dBm$ formula to transform RSSI value to power, and vice versa. While in Intel cards the RSSI value uses actual received power in the negative dBm scale. In this study, we refer the RSSI value to actual received power without applying any formula.

Jain's Fairness Index - Another criteria which we implemented in this study is well known Jain's fairness index introduced in [14]. Th_i is the throughput of the i^{th} intersection and $J_i \in \mathcal{J}$.

$$J_i = \frac{(\sum_{j=1}^{p_i} \frac{n_j}{c_j^{max}} max(Th_j))^2}{p_i \sum_{j=1}^{p_i} (\frac{n_j}{c_j^{max}} max(Th_j))^2} \quad (1)$$

Since each intersection has its own stationary set of APs, the aim is to balance the fairness index within the APs. In other words, each STA has only a limited chance to handover between APs (i.e. within the intersection). Therefore, considering fairness in ESS is inconvenient since we can not associate STAs to every APs. The value of Jain's index ranges from $1/p_i$ to 1. If all APs within the intersection i is balanced, then the value will be 1. In the same way, the worst degree of load balancing is $1/p_i$, where p_i is the number of APs in the intersection i.

Number of STAs - Even if a number of STAs is not a crucial value for BSS load determination, it is an important criterion to understand the number of connections on APs. Therefore, the number of STAs is also added to among DT model features like RSSI value. Since the number of associated STAs affects various network metrics such as throughput, rtt, loss rate etc.

Packet Delivery Ratio (PDR) - PDR is a ratio of correctly received packets to the total number of packets. It is mostly used to determine link quality and the load of BSS. And in the low data rates, PDR presents a strong correlation with RSSI value. However, with the higher data rates, the correlation is lost. Consequently, RSSI can not be used to estimate PDR value. Thus in this study, we include PDR as a feature in DT model.

Bit Error Rate (BER) - If there are various lengths of packet sizes in the ESS, the PDR metric may fail to observe link quality [13]. Therefore, we introduce another crucial metric to be used in DT model: bit error rate, or simply BER. BER is a ratio of the number of erroneous bits received over the total number of received bits. PDR metric also measures error packets, it makes a course-grained observation compared with BER. Thus, bit-level analysis is also important.

Average Packet Loss Rate ($\widetilde{Lr}$) - Another important criterion for load balancing decision is packet loss rate. Since packet loss rate dramatically affects the quality of service in real-time applications, the average packet loss rate of each BSS is calculated as follows,

$$\widetilde{Lr} = \frac{\sum_{i=0}^{n_i} Lr}{n_i} \tag{2}$$

$$Lr = 1 - (Lr - P_\epsilon * (1 - Pc)) \tag{3}$$

P_ϵ is the packet error rate and P_c is the collision probability.

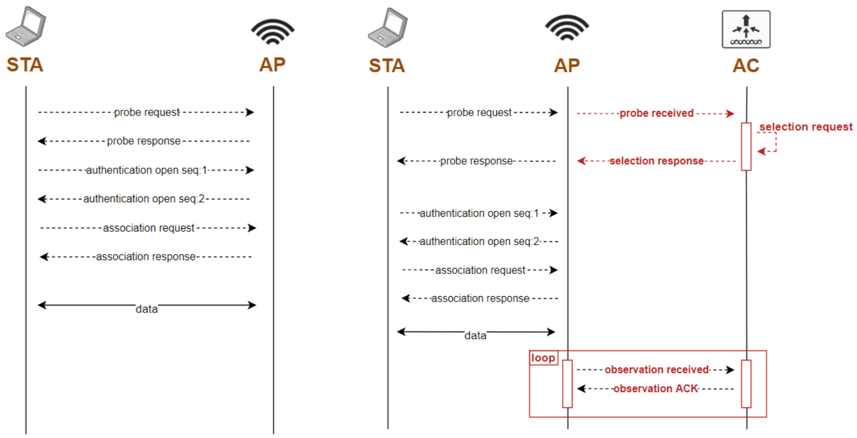
Normalized Throughput ($\widehat{Th}$) - In order to obtain normalized throughput of APs, we use Bianchi's model, which constructs a two-dimensional Markov model to analyze the saturated system throughput of a BSS in IEEE 802.11 with Distributed Coordination Function (DCF) mechanism. According to Bianchi's model [15], the normalized throughput of i^{th} BSS is as follows;

$$\widehat{Th_i} = \frac{P_{ts} P_{tr} E[P]}{(1 - P_{tr})\sigma + P_{tr} P_{ts} T_s + P_{tr}(1 - P_{ts} T_c))} \tag{4}$$

where P_{ts} and T_{ts} is the probability and average time duration in the case transmission is successful. Also, P_{tr} is the probability that there is at least one transmission within the given time, T_c is the average time of collision, σ is the slot duration.

The probability of having at least one transmission is calculated by $P_{tr} = 1 - (1 - \tau)^{n-1}$. And τ is probability that a STA attempts to transmits within the time duration.

Average Round-Trip-Time (RTT) - One of the aims of WiFi6 is to provide high efficiency in time-sensitive applications, such as high-quality videos, AR/VR applications, and real-time streaming. Therefore, round-trip-time plays a crucial role in determining this service differentiation and the load of APs.



(a) Legacy way of association (b) The proposed association procedure

Fig. 3. Two association methods

4.2 Association Control

Legacy Way of Association. In order to understand the contribution to the proposed Association Control mechanism, the two legacy ways of association in IEEE 802.11ax is shown in Fig. 3. Since in the passive scanning the STA sees each AP with their beacon packets, APs can not be chosen before the STA meet with the AP. Therefore, our proposed association scheme is based on the active scanning mechanism as presented in Fig. 3b. Red colors indicate the proposed control packets. In the association procedure, there are two cases: association of new STA and re-association of existing STA. The details of the two cases are as follows.

The Proposed Association Procedure: New STA Association. When a STA wants to connect to WLAN, it first sends a "probe request" and then waits for the "probe response". During this waiting time, AP sends "probe received" message through an *interface* of the proposed AC. Then, the AC selects an appropriate AP based on the DT output. Only the selected AP sends "probe response" message to the STA, unlike the legacy in which all APs hearing the probe request message response. After that, legacy authentication (if any) and association handshake are invoked.

The Proposed Disassociation - Association Procedure: Existing STA Association. One of the steps of load balancing is to consider existing STA-AP distribution. Since the load of BSS might change instantly, robust load balancing scheme should consider both new and existing STA associations as shown in Fig. 4.

Trigger: Load balancing for existing STAs differ from the new STA association. Because the trigger for new STA association is simply "probe request". On the other, there is no straightforward way to decide in what point the proposed algorithm should operate for existing STA association. Some of the studies use predefined period to balance load in the WLAN. Another frequently selected aspect is using Jain's index. If Jain's index within the WLAN exists some threshold, then the algorithm is run. However, one inclusive Jain's index might not mean that there is an imbalance situation in all overlapping WLANs. Therefore, we propose a new trigger point to only consider intersections which have imbalanced load problem. First, $\forall J_i \in \mathcal{J}$ is calculated. Second, the ascending ordered $\overline{\mathcal{J}}$ is obtained. Then, $J_j = min(\overline{\mathcal{J}})$ is selected so that worst balanced intersection will be the starting point. After selecting worst balanced intersection, candidate set of STAs is selected to shift from the associated AP to the new less loaded AP within the same intersection. The next step is re-calculating Jain's index for all intersections and processing in the same way. Note that after set of handovers, load of APs and Jain's index of intersections likely to change. In order to prevent "butterfly effect" caused by set of handovers, only one intersection is aimed to be balanced. If the same intersection is selected again after calculating Jain's fairness index one again, then second minimum Jain's index is processed. This process is continued until all intersections are balanced according to some predefined threshold, T_f.

Candidate Strength Parameter: In order to determine candidate STAs to be shifted from the current associated AP to the less loaded APs. Most studies simply select STAs which have less RSSI value. This also indicates a STA placed on the cell-edge is selected first for handover process. However, selecting STAs with low RSSI values is a similar idea to associate a STA with highest RSSI value. In other words, RSSI value shows poor performance in any association process because it is a weak metric stand-alone to define the load. We also propose a new metric named, candidate strength parameter, γ, to present a strength of a STA for handover process. Following formula shows the candidate strength parameter for i^{th} STA to handover to less loaded AP_j.

$$\gamma_i = \frac{\overline{P_j} + \overline{T_j}}{2} + RSSI_{i,j} \quad (5)$$

where $\overline{P_j}$ and $\overline{T_j}$ is the normalized packet loss rate and throughput in AP_j. The value of γ varies -1 to 2, where minimum value indicates a STA is shifted to the AP_j.

Candidate APs: Note that the proposed *gamma* parameter is only calculated for STAs which has selected less loaded AP_j in own candidate APs list. The candidate APs of i^{th} STA, C_i, defines the set of APs in which covers the STA with acceptable link quality. Let T_r is the RSSI value threshold to determine acceptable link quality in between STA and AP. The APs having the RSSI value above the threshold are considered as the appropriate candidates for association.

In this study, we use $T_r = \{-70, -75, -80\}$ different thresholds to evaluate the performance.

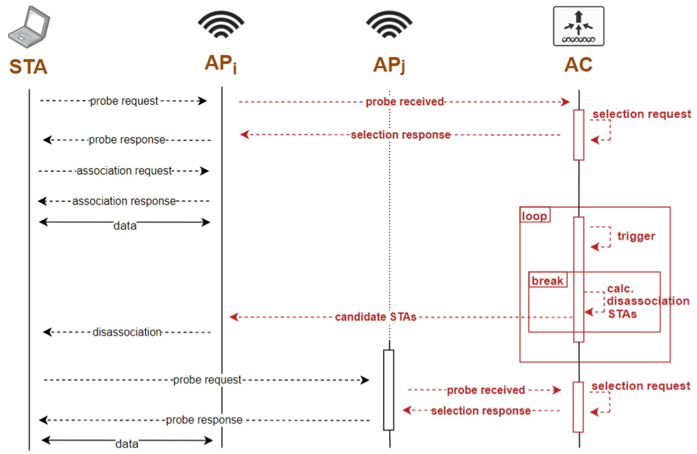


Fig. 4. The proposed disassociation - association procedure

4.3 Adaptive CST Control

In the scope of AC decision scheme, adaptive CST tuning is another module to decrease overlapping co-channel interference between APs. AP loading scheme without adaptive CST tuning is prone to OBSS interference, which considerably affects QoS of STAs and transmission quality. Therefore, AC first initialized all BSS with default CST, which is -82 dBm for 20 Mhz channel and increments 3 dB with the channel is doubled. Each new association attempt first runs DT model with the given input. Then association and authentication packets are sent to the AP according to new association decision. Finally Adaptive CST Control algorithm is triggered according to mechanism described in [16] to provide fair channel contention in dense WLANs. Since edge-cell STAs are most vulnerable to unfair channel access followed by low throughput, adaptive tuning of CST value is crucial part of the AC scheme. In the work [16], we alternated the $UpdatePeriod_{\alpha}$ value, used in local scale update period, with the new association timer. By this way, BSS and STAs scale own CST value to decrease co-channel interference caused from OBSS.

5 Evaluation

The ns-3 [16] network simulator is used in this experiment due to adaptive features for IEEE 802.11ax networks. We also used 20Mhz channels with overlapping WLANs with same channel. In this section, we evaluate the performance of our proposed AC scheme in dense WiFi6 WLANs in terms of the average

Table 2. Simulation parameters

Parameter	Value
Number of APs	19
Number of STAs	570
STA density	30 STAs per AP
Channel Band	2.4 GHz
Mobility	Exists as described
AP/STA Tx Power	20/15 dBm
Number of antennas	SISO
Packet	1464 bytes
Beacon Interval	102.4 ms
Guard Interval Duration	1.6 us
Modulation	256-QAM
Management	All APs belong to the same management entity

throughput per STA, and average Jain's Fairness Index. We used the indoor Small BSSs Scenario for dense WLANs [17] proposed by IEEE 802.11ax Task Group (TGax). Other simulation parameters can be found in Table 2.

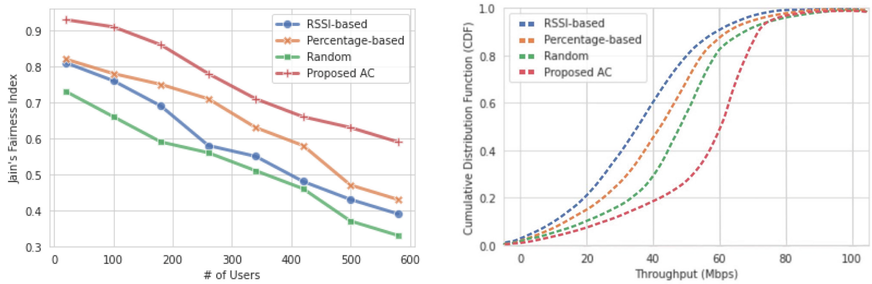
The ML model is trained using 61000 samples and tested over 18100 samples. Since each intersection has at most 4 APs, the number of labels vary 2 to 4. We use ID3 decision tree model. Thus we split dataset according to Information Gain (i.e. Entropy) value. Moreover, we prefer to use Cost Complexity Pruning (CCP) technique.

5.1 Results

In order to compare the performance of the proposed AC scheme, we used three baselines. RSSI-based association mechanism is the traditional way in IEEE 802.11 WLANs explained before. Percentage based scheme is another candidate method discussed by IEEE task group [17]. According to percentage based association STA associations are divided into three group with defined percentages. X% of STAs are associated with the strongest AP, then Y% of STAs are associated with the second-strongest AP, so on so fort. And final baseline is random association scheme in which STAs are randomly chosen and associated to the less loaded AP.

We perform 50 simulations for each method with same conditions to observe the performance of each baselines. Since there are two different associations way, half of simulations implement new STA associations; other half for existing STA associations. Then average of each test results are calculated to plot the final result.

Figure 5a shows the variation of the Jain's fairness index with increasing number of STAs. When the number of STAs increase, it is clear to observe



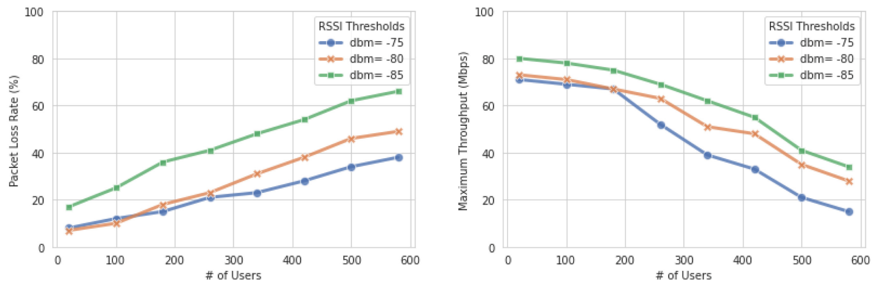
(a) Jain's fairness index with increasing STAs

(b) CDF by increasing STAs

Fig. 5. Comparison with baseline methods

dramatic decline due to ascending channel competitions. As it is expected AC scheme gives superior result thanks to adaptive CST mechanism, which directly aims to increase fair transmission between STAs. Another observation is that RSSI-based scheme gets higher Jain's index compared to random scheme. This results also shows the importance of RSSI metric in the association and load determination. But it also shows it has shortfall by comparison with the proposed AC scheme.

Figure 5b plots the cumulative distribution function of the total network throughput when the number of STAs is 20 per APs. The results is the average from 50 simulation runs, with half of them is new STA association and other half is the result of existing STA association. It can be observed that the percentage gain of the proposed AC scheme is quite large. Because the proposed AC scheme can find the STA-AP association set by using various critical metrics. Therefore, the proposed scheme can not only provide fairness balance among BSSs but also increases QoS.



(a) Packet loss rate of different RSSI thresholds

(b) Maximum throughput of WLAN with different RSSI thresholds

Fig. 6. Analysis of RSSI threshold used by STA's to form candidate AP list for handover

The last experiment set measures the effect of the network with changing RSSI thresholds, T_r. Since RSSI threshold directly affects the possible associations of a STA (i.e. candidate AP list), it most likely have an impact on the network and transmission performance. Consequently, Fig. 6a shows worst packet loss rate performance in $T_r = -85$ dbm. When lower T_r values, number of options for STAs to associate APs increases. Then with the adaptive CST mechanism, packet loss rate tends to increase. However, the throughput results present exact opposite implications. Figure 6 indicates that having larger candidate AP list does not affect the maximum throughput in the WLAN. In other words, higher values of threshold has a negative impacts on maximum throughput and leads to inefficient usage of the network. Therefore, this analysis shows that lower values of the threshold which is used for creating candidate APs list is suggested.

6 Conclusion

This study provides a complete association management scheme including adaptive carrier sensitivity considering both new STA association and existing STA association. In order to monitor underlying ESS, the proposed access controller (AC) takes related QoS and network parameters from APs via an interface and builds a decision tree model. The features are carefully selected and particular decision models are trained for each overlapping areas (i.e. intersections). After that we introduce a new metric called as candidate strength parameter to select a set of STAs for re-association. Finally we evaluate the proposed AC scheme with three baselines: legacy RSSI-based association, percentage based association, and random disassociation. Then we compare the various RSSI thresholds to observe the system performance. The results show that the proposed AC scheme gains 6% and 14% improvement in Jain's fairness index and throughput, respectively.

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