



Cao, F., Zhong, Z., Fan, Z., Sooriyabandara, M., Armour, S., & Ganesh, A. (2016). User association for load balancing with uneven user distribution in IEEE 802.11ax networks. In *2016 13th IEEE Annual Consumer Communications and Networking Conference, CCNC 2016: Proceedings of a meeting held 9-12 January 2016, Las Vegas, NV, United States* (pp. 487-490). Article 7444828 Institute of Electrical and Electronics Engineers (IEEE).
<https://doi.org/10.1109/CCNC.2016.7444828>

Peer reviewed version

Link to published version (if available):
[10.1109/CCNC.2016.7444828](https://doi.org/10.1109/CCNC.2016.7444828)

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User association for load balancing with uneven user distribution in IEEE 802.11ax networks

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Abstract— This paper proposes a dynamic user association method to address the load balancing problem in dense IEEE 802.11ax networks with uneven user distribution, where a user determines which AP to connect to taking into consideration of multiple factors such as RSS, potential relative capacity, achievable data rate and location of users. The method is user-centric and does not incur much signaling overhead, while performance optimization can be achieved without inter-AP coordination. Simulation results have been presented to show that the proposed solution can improve load balancing and have higher average throughput for 10% worst users as well as maintain the maximal total system throughput. Our evaluation also suggests that the location-awareness of users considered in the proposed solution plays an important role to improve the performance.

Keywords— 802.11ax, user association, load balancing

I. INTRODUCTION

Recently IEEE has started a new standard group called 802.11ax to design high efficiency WLAN systems in future high capacity and dense deployment [1]. In dense networks, neighboring access points (APs) will get closer and serve many more users, and the user distribution among the APs is likely to be uneven. Uneven user distribution can lead to system inefficiency, which will become more prominent with huge number of WiFi devices. User association can be used for load balancing among the neighboring APs which is a key strategy to improve system efficiency.

Traditionally, when a user powers on or tries to reconnect to a network, the user will scan the signals from APs and choose to connect to the AP that has the strongest received signal. This received signal strength (RSS) based user connection can cause traffic concentration among the APs, especially with uneven user distributions, which consequently leads to congestion and performance degradation. How to better balance the loads among the APs through user association is of great interests, especially for highly dense deployment. Efforts have been made to improve the performance based on the RSSI-based method [2][3] (threshold based RSS association in [2] and MU-MIMO-based association in [3]). However, the above methods cannot improve load balancing, if not worsen it. Meanwhile, centralized approaches [4-6] try to maximize performance with global optimization, and require full AP collaboration to exchange relevant parameters which may not be practical for

most WiFi applications. On the other hand, distributed approaches have been proposed attempting to improve system performance through local optimization [7-9]. However, these methods often lack consideration for dynamic situations where the number of active users will change during the communication.

This paper proposes a dynamic user association method wherein a user determines which AP to connect to, taking into consideration of multiple factors such as RSSI, link quality, and location of the users. The method is user-centric and hence has minimal change from the perspective of signaling overhead, while performance optimization can be achieved without inter-AP coordination. Unlike conventional approaches, the proposed method has distinguished itself with the following features:

- 1) Instead of choosing to connect to the AP that has the highest RSS, a user intends to associate with the AP based on the highest potential relative capacity to maximize user performance, based on the achievable rate and the number of users served by each AP.
- 2) Combining with the highest potential relative capacity, the user will further take into account its ‘location’ within the coverage of the AP with the highest RSS, to balance the system performance in terms of overall throughput of each AP.
- 3) The proposed method dynamically covers the new users as well as existing users, being adaptive to the change of the number of active users.

The rest of the paper is organized as follows. Section II details the proposed user association method for both new user case and existing user case and Section III provides simulation results to demonstrate its performance. The paper is concluded in Section IV.

II. USER ASSOCIATION

We consider a network with I APs and there are N active users in total. Each AP i serves a cell comprising a set of active users Ω_i , and $N_i = |\Omega_i|$ is the number of active users AP i serves and $N = \sum_{i=1}^I N_i$. We assume that the AP i knows the RSS $S_{i,n}$ ($n \in \Omega_i$) for each of its serving user n either from feedback or estimation of uplink transmitted signal. Each AP i will broadcast two parameters N_i and S_i through control

signaling, where S_i is the average RSS (ARSS) among the served users in Ω_i , i.e. $S_i = \frac{\sum_{n \in \Omega_i} S_{i,n}}{N_i}$.

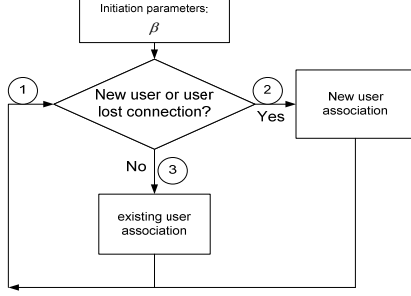


Fig. 1: Outline of the proposed user association method

We consider two scenarios for a given user to connect to an AP. In the first scenario, a user just powers on or has lost connection, and wants to find an AP to connect. In the second scenario, a user has been associated with an AP, but would like to transfer to another AP due to certain reasons, e.g., better throughput. An outline flowchart of the user association process is illustrated in Fig. 1.

Now we describe the proposed user association method for both new user and existing users.

First scenario: New user case

Assuming the new user is denoted by k , the method is composed of the following steps.

- a) User k gets the parameters N_i and S_i from control signaling from surrounding APs, measures the RSS S_{ik} and the signal to interference plus noise ratio $SINR_{ik}$. It then estimates the achievable data rate r_{ik} from the surrounding APs, where $r_{ik} = f(SINR_{ik})$ and $f(\bullet)$ is a function with respect to $SINR_{ik}$, which could be obtained from a lookup table or a capacity formula.
- b) User k then calculates the potential relative capacity as $R_{ik} = \frac{r_{ik}}{N_i + 1}$ and finds the AP that can provide the highest potential relative capacity denoted by $i^* = \operatorname{argmax}_i R_{ik}$, and the AP that has the highest achievable data rate denoted by $j^* = \operatorname{argmax}_i r_{ik}$.
- c) User k determines the AP that it connects to based on the following rules:
 - If the two APs are identical, i.e., $i^* = j^*$ the user will choose AP i^* to connect.
 - Else $i^* \neq j^*$
 - If $S_{j^*k} < \beta \times S_{i^*k}$, the user will choose to connect to AP j^* , otherwise the user will connect to AP i^* , where β is a predefined value.

The basic idea for the new user case here is that, when a new user k wants to access the network and connects to an AP, the user in step a) will calculate the achievable data rate r_{ik} that it can get from the surrounding APs based on the $SINRs$. Further in step b) it calculates the potential relative capacity R_{ik}

with the estimated achievable data rate and the number of serving users N_i . Then the user will find out which AP that can provide the highest potential relative capacity and which AP that has the highest achievable data rate. In step c) the user will decide to connect to the latter AP if it is not a ‘‘cell edge’’ user in the coverage of the latter AP by comparing the user’s RSS with β times the ARSS of the latter AP. Otherwise the user will connect to the AP that can provide the highest potential relative capacity. It should be noted that the potential relative capacity is not the real capacity the AP is able to provide, instead it is just a metric to demonstrate relative capacity among the APs and from it we can roughly know which AP has higher capacity and which AP has lower capacity for a new user.

In our proposed method, the new user will take into account of its location and potential relative capacity when it attempts to connect an AP which is reflected in step c). A new user who is a cell center user will connect to the AP based on the strongest RSS (or highest achievable data rate), and a new user who is a cell edge user will associate with an AP with the highest potential relative capacity. The intuition behind this can be explained in Fig. 2 as follows.

In practice, new users show up sequentially instead of simultaneously. In our example, suppose there are 2 APs (AP1 and AP2), and AP1 is serving 5 users and AP2 is serving only one user in Fig. 2(a). Two new users (cell center user 7 in the shadow area and cell edge user 8 shown in the figure) turn up and assume that AP2 can provide higher potential relative capacity for them. With RSS-based association, the two users will connect to AP1. On the other hand, without location-awareness, the two users will connect to AP2 based on highest potential relative capacity. Intuitively, it would be a better solution if new user 7 connects to AP1 and new user 8 connects to AP2, and existing user 1 switches to AP2 as shown in Fig. 2(b). With our proposed method, we can keep new user 7 to be served by AP1 and new user 8 to be connected to AP2. How to switch user 1 from AP1 to AP2 is about the re-association among the existing users which is described in the following.

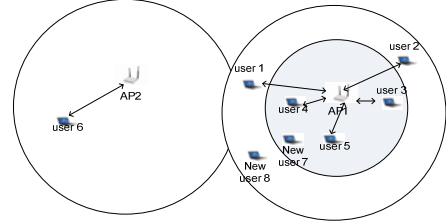


Fig. 2(a) : Example of new user association

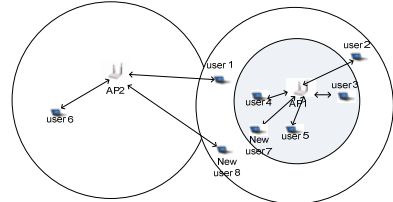


Fig. 2(b): Preferable user association

Second scenario: Existing user case

Assume the existing user k has been connected to an AP with index of m , where $k \in \Omega_m$.

- d) User k scans the signaling from surrounding APs and its serving AP periodically (or based on a trigger, for example, the number of users served by its serving AP has changed), obtains the parameters N_i and S_i from the control signaling, measures the received signal strength S_{ik} and $SINR_{ik}$, and estimates the achievable data r_{ik} .
- e) The user then calculates the potential relative capacity R_{ik} and finds the AP that can provide the highest potential relative capacity denoted by $i^* = \operatorname{argmax}_i R_{ik}$, where the potential relative capacity will be calculated as $R_{ik} = \frac{r_{ik}}{N_i}$ if $i = m$, otherwise $R_{ik} = \frac{r_{ik}}{N_{i+1}}$.
- f) The user decides whether to switch to a new AP based on the following rules:
- if The two APs are identical, i.e., $i^* = m$ continue to stay with the serving AP and wait until the next scan.
- else The user will choose to connect to AP i^* with probability p where p will be higher if the RS from AP m is smaller, and one example to determine p can be:

$$p = \frac{S_m}{S_{mk} + S_m}.$$

Similar to the steps a) and b) in the first scenario, for an existing user associated with a serving AP, the user will scan the surrounding APs in step d) and e) and then check if there is any other AP that can provide better potential relative capacity in step f). If there is one, the user will switch to the new AP with a probability p , which is inversely proportional to the RSS from the serving AP. How to switch with a given probability p can be implemented like this: the user will generate a random number α with uniform distribution in the range of (0, 1), and compare it with p . If $\alpha \leq p$, the user will switch to the new AP, otherwise it stays with its serving AP and waits until the next scan period. The switching probability is used here to avoid multiple user simultaneous switching and ensure that a user which is further from its current serving AP has higher probability to switch over.

III. SIMULATIONS

A. System Setup

We consider a network with 7 APs as shown in Fig. 3 where the distance between each access points is 40 meters and the users are randomly dropped within the 30m square centered by every AP. To model uneven user distribution, the probability that a client is dropped within the square of the center AP is significantly higher than that of other APs. The purpose of this topology is to simulate the practical scenario of a meeting environment: most of colleagues are in the meeting area and only some staff members are still working in their offices. It is assumed that each AP uses different channels. According to this assumption, cells are on 7 different channels.

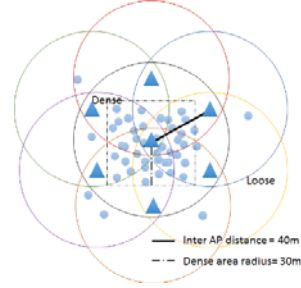


Fig. 3: The network layout

Three methods, namely, RSS-based, client number balance (CNB), and the proposed algorithm, are tested in this scenario to compare the performances. The RSS-based user association method is the default method for a client to choose which AP to connect based on the highest RSS. With this method, users will be congested to the AP who is placed in the center of the crowded nodes and this may be a fairly bad choice for a user who is expecting a better user experience. As for the CNB method, a client will choose to connect to the AP with the least number of connected clients. In this case, the traffic may be balanced in terms of transmit opportunities. The throughput, however, may not be balanced by this method, because the link capabilities of users are not fully utilized.

The main parameters of the simulated system are listed in the table below, which are consistent to those of a realistic IEEE 802.11ac system with single antenna configuration.

TABLE I: PARAMETERS USED IN SIMULATIONS

Parameter	Value
SIFS/ Slot time	16μs/9μs
DIFS	SIFS + 2*Slot time (34μs)
Propagation delay	1 μs
RTS/CTS	Disabled
ACK Timeout	300 μs
Carrier Sense threshold	-76dBm
Data header	272 bits
CW backoff index	[5, 10] equivalent to CW [31,1023]
ACK size	(2+2+6+4)bytes = 112bits
Payload	fixed data transmission time
Data Rate	“backed-off” Shannon capacity
Constant transmit power	70mW
Operating frequency f_c	2.4GHz
Antenna gain	0dBi
Number of Aps/client	7/144
Noise figure	3 dB
Bandwidth	20MHz
Shadowing	Log-normal (5 dB standard deviation)

The achievable rate is calculated by a “backed-off” Shannon channel capacity, which is given by

$$C = \begin{cases} \rho * \log_2(1 - \gamma_1) & \gamma < \gamma_1 \\ \rho * \log_2(1 + \gamma) & \gamma_1 < \gamma < \gamma_2 \\ \rho * \log_2(1 + \gamma_2) & \gamma_2 < \gamma \end{cases}$$

where ρ is the parameter (between 0 and 1, 0.6 here in our simulation) selected to match the link level performance, and γ is the instantaneous post-processing SINR which is determined as a function of assumed receiver type (e.g. MRC or MMSE). The capacity is a “backed-off” Shannon channel capacity where $10\log_{10}(\gamma_1) = -0.5 \text{ dB}$ and $10\log_{10}(\gamma_2) =$

22 dB, taking into account of the non-ideal receiver structure without the need to simulate MCS selection.

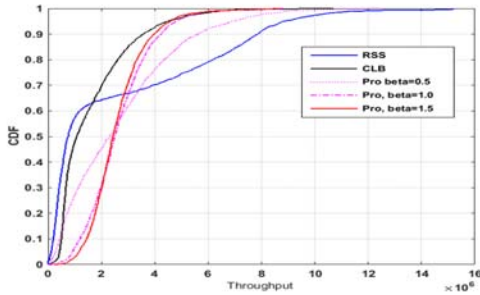


Fig. 4: CDF of node throughput

B. Simulation Results

In the simulations, the users are dropped according to the system topology setup and the communications between the users and APs are simulated with 802.11ac CSMA protocol with the system parameters in Table I, then the performance metrics we are interested here are CDF (cumulative distribution function) of node throughput, average total throughput (equivalently average node throughput) and the average throughput of 10% worst users. The CDF of node throughput is used to illustrate the distribution of node throughput which can demonstrate the fairness and load balancing among the users. While the average total throughput illustrates the whole system performance, the average throughput of 10% worst users is used to check how well the 10% of worst users perform and is an important metric for user experience.

we tested the performance for RSS-based, CNB, and the proposed method. In the proposed method, the results are also shown with different β values. Fig. 4 shows the CDF of node throughput including APs and users where we can see that the throughputs of individual nodes are more balanced when the proposed algorithm is used. It is expected that the default RSS-based method has the worst balance performance among the nodes. Meanwhile the total system throughput is shown in Fig. 5, whereas the proposed solution maintains almost the same total throughput as the RSSI-based method and is significantly better than the client number balance method.

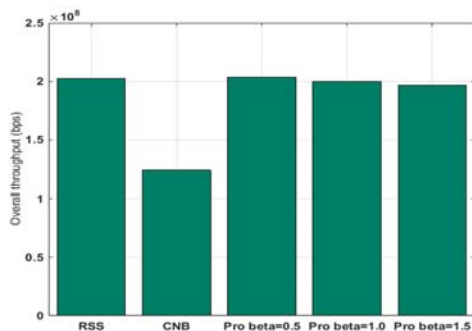


Fig. 5: Total throughput

The throughput of the 10% worst performing clients is depicted in Fig. 6. The figure shows that the proposed method performs best for the worst users so long as proper β value of

the algorithm is selected. Especially it can achieve significant improvement over the RSS-based method.

Overall our simulation results illustrate that the proposed algorithm provides not only more balanced user/node throughput than the RSSI-based method, but also better total throughput performance than the client number balance method. The system parameter β has significant impact on the overall throughput performance, which also suggests that the location of users (cell-edge or cell-center) is critical for user association in the perspective of load balancing.

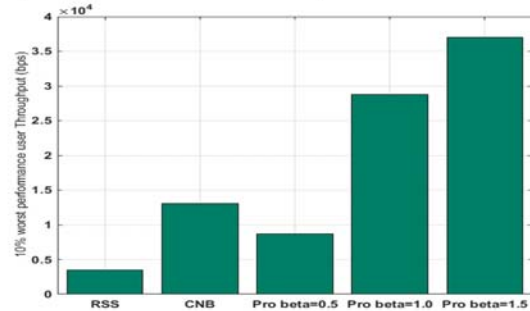


Fig. 6: The average throughput of 10% worst users

IV. CONCLUSION

In this paper we have proposed a user association method to balance the loads among the cells/users for dense 802.11ax networks with uneven user distribution. This method takes into account of a couple of factors including RSS, link quality, and the location of the users to determine which AP to connect to. The method is user-centric and there is no need for inter-AP coordination, hence has minimal change from the perspective of signaling overhead. Simulation results show that the proposed solution indeed can improve load balance, has higher average throughput of 10% worst users as well as maintain the maximal total system throughput.

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