User Association in Software-Defined Wi-Fi Networks for Enhanced Resource Allocation

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***Abstract*—Although 4G and 5G Radio Access Technologies (RATs) aim to usher in faster connectivity that is able to cope with mobile traffic demands, this capability is sometimes hindered by poor indoor signal quality caused by distance from base stations and the materials used in the construction of buildings. These factors have led to Wi-Fi being adopted as the technology of choice in indoor scenarios. Although the deployment of Wi-Fi Access Points (APs) can be planned, the user-AP association procedure is not defined by the standard but left to the vendor's choice, which for simplicity is usually driven by signal strength. This approach leads to uneven user distributions and poor resource utilization. To overcome this rigidity, in this paper, we leverage Software-Defined Networking (SDN) to propose a joint user association and channel assignment solution in Wi-Fi networks. Our approach considers average signal strength, channel occupancy, and AP load to make better user association decisions. Experimental results have demonstrated that the proposed solution improves the aggregated goodput by 22% with respect to approaches based on signal strength. Furthermore, user level fairness is also improved.**

***Index Terms*—Wi-Fi, SDN, IEEE 802.11, WLANs, mobility management, load balancing, user association**

I. INTRODUCTION

Modern society is moving towards a wireless world empowered by recent market trends. Nowadays, smartphones, laptops, smartwatches and other portable devices incorporate at least one Radio Access Technology (RAT). Despite the high transmission rates promised by 4G and 5G technologies, there is no doubt that Wi-Fi has taken a major step forward in indoor scenarios where cellular connectivity is susceptible to suffering performance drops due to the distance from the base stations and the materials used in buildings. Nevertheless, the unplanned nature and unlicensed operation of Wi-Fi results in suboptimal performance in dense environments as the number of channels in the 2.4 GHz and the 5 GHz bands is limited.

When two or more Access Points (APs) are in the same collision domain, i.e., within carrier sensing range, interference and collisions become one of the most significant causes of performance degradation. This problem is aggravated by uneven distribution of traffic and users across the APs due to congestion of the physical medium. Therefore, an efficient network resource allocation in terms of both channel assignment and user association is highly important. In our previous work [1], we discussed the relationship between channel utilization and network performance. In particular, it was shown how delivery ratio drops when channel occupancy is over 60% due to the number of collisions and the decrease in the physical datarate chosen by rate selection algorithms, thus leading to greater channel occupancy and lower throughput.

User association in Wi-Fi follows a user-driven approach, in which stations select the AP with the highest Received Signal Strength Indicator (RSSI). However, one should note that signal strength completely hides the information about the status of the wireless medium and the network resources. Moreover, this is a local factor which makes the coordination across APs and their management more difficult. Thus, it may result in unbalanced load distribution and a decrease in performance.

Despite the variety of solutions tackling this problem, innovation is usually limited by compatibility with the standard. Although backwards compatibility has facilitated the success of Wi-Fi in the market, adhering to traditional network architectures limits novelty and improvements. Software-Defined Networking (SDN) has been born with the aim of redesigning networking functions by decoupling the data-plane from the control-plane and introducing a centralized controller that consolidates information about the whole network. In addition to simplifying network management, this approach also allows the deployment of network applications and services in a programmatic way.

In this work, we present a new SDN-based user association scheme that takes Wi-Balance [1] as its basis. Although Wi-Balance is based on SDN principles, it fails to consider network-wide signal strength and channel traffic load, which makes it lose efficiency as the network grows. This new approach aims to solve these problems by jointly accounting for APs and channels traffic load while keeping a good average signal strength. This is achieved by relying on efficient user association procedures to obtain a solution that has been proved to improve network resource allocation and network aggregated throughput.

The rest of the paper is organized as follows. Sec. II provides an overview of the related work. In Sec. III the proposed solution and the design principles are explained. In Sec. IV the results from the real-world performance evaluation are discussed. Finally, conclusions are given in Sec. V.

This work has been supported by the Spanish Regional Government of Castilla-La Mancha under the project SBPLY/17/180501/000353, the Spanish Ministerio de Ciencia, Innovación y Universidades and the European Commission (FEDER funds) under the project RTI2018-098156-B-C52.

II. RELATED WORK

Association schemes in Wireless Local Area Networks (WLANs) have been the object of study of a considerable body of literature pursuing diverse goals. For instance, the authors in [2] try to balance the load among the APs to achieve user bandwidth fairness. For this purpose, each station must specify its bandwidth requirements for the current session. Based on this, stations are associated with the APs that can achieve such requirements in a more unrestrained way while maximizing overall traffic. The same target is pursued in [3], in which the authors propose an algorithm that aims to minimize the number of stations per AP based on signal strength. However, the proposal in [2] is set to be more efficient as the number of attached clients is not an accurate estimator of the workload of an AP since each client may generate different amounts of traffic.

The authors in [4] also try to balance load at the AP level. By means of an SDN centralized controller, they fill a scoring matrix that takes into account both RSSI and occupancy rate. Stations join the APs with the highest score. These approaches include signal strength as part of their decision making. Nonetheless, this may lead to ping-pong effects, which are difficult to handle without coordination between the APs. This effect is tackled in [5], in which a handover is not carried out until the same AP has been defined as the best choice for n consecutive times. In [6], the authors study the impact of a smart AP selection algorithm that runs on top of an SDN framework. A Fittingness Factor parameter is defined to optimize the standard deviation of the network to maintain overall network performance.

In [7] and [8], the authors also propose approaches based on signal strength, but in this case the decision is taken on the station side. This is not optimal as they do not consider network-wide performance. In [9], the authors propose a distributed scheme that aims to adapt the transmission power of the APs to tune the cell size according to their load and their neighbours' for its balance, producing the migration of stations from the most loaded APs to their less loaded neighbours. This method is known as Cell Breathing. The problem of their proposal is the difficulty of its implementation as the APs must compute their load and communicate it to the rest of the APs. A centralized approach using SDN would solve the problems in the implementation, making it more efficient. This is the case of [10], in which a combination of Cell Breathing and SDN is presented.

Other approaches aim to improve network performance by using network load instead of signal strength. This is the case of [11], in which by using an SDN architecture the authors force handovers from the most loaded APs to the least loaded ones. This is also the case of [12], in which the average workload of the network is used to redistribute traffic when a new station joins the network. However, they also look into signal strength in case it deteriorates excessively. Nonetheless, modifications in the standard beacon frames are required. In [13], the AP sends load status reports to an SDN central controller whenever a new station connects to the AP or the difference between the previous and the new load exceeds a threshold. The SDN controller computes fairness and if it is not close to 1, it dispatches stations from overloaded APs to underloaded ones.

Handovers usually produce a reassociation process that involves a period of time during which the migrated station has no connection. To deal with this problem, the authors in [14] propose an approach in which association decisions are driven by RSSI although it requires that the APs operate on non-overlapping channels. However, having all the APs operating in the same channel has a very negative effect in channel occupancy as all the stations in the network share the same physical medium. To deal with this problem, the authors in [15] introduce the concept of Virtual Access Points to allow seamless handovers while setting different channels for each AP. In [16] SDN is leveraged for seamless handover together with a centralized reassociation algorithm that is network-wide aware to reduce interpacket delays and provide QoS based on a Markovian analytical model.

Most of the problems tackled in this paper are aggravated in dense networks such as universities or office buildings where Enterprise WLANs (EWLANs) are deployed. In this regard, the authors in [17] present an SDN-based approach focused on EWLANs that takes into account the number of users per AP, and the channel load at the AP level. This is inefficient as other APs in the same collision domain also use channel time and could overload the channel, resulting in throughput degradation. Even more metrics are combined in [18] in which RSSI, potential capacity, achievable data rate and location of users are considered for association decisions.

Link quality and interference are also very important in order to unlock the full potential of wireless networks. In [19], the authors present a load balancing algorithm that selects different network interfaces for each flow based on the required QoS, available bandwidth and link quality in order to find the best possible path for all flows, maximizing overall throughput. In [20], the authors also aim to maximize aggregated throughput. To do this, stations seek the AP with the gratest available bandwidth. This approach seems to be unfair and not optimal. However, seeking the AP with the greatest available bandwidth implicitly implements least-load-first AP selection. The authors in [21] also aim to maximize the use of spectral resources in cases of congestion by using an alternative primary channel where the stations can obtain transmission oportunities (TXOP) when it is idle even when the primary channel is busy.

The number of works on this topic is considerable, but as shown in this section they have many different goals to improve network performance. Our approach aims to improve network performance by carrying out a trade-off between AP load, channel load and average signal strength to obtain a more versatile approach that performs better in most situations. Furthermore, we also aim to ensure seamless handovers to contribute to higher performances and to minimize interference through an efficient channel distribution.

III. USER ASSOCIATION FOR ENHANCED RESOURCE ALLOCATION

This work aims to improve the performance of our previous approach: Wi-Balance [1]. To this end, in this section we first introduce the main features of the Wi-Balance association scheme. Then, we describe the issues identifed in Wi-Balance. Finally, we introduce a new algorithm to solve these problems.

A. Wi-Balance

Wi-Balance is an SDN-based solution for joint user association and channel assignment in Wi-Fi networks. The performance evaluation undertaken by this solution showed that this approach outperforms RSSI-based association schemes by efficiently assigning and limiting collision domains, which reduces interference and collisions. Furthermore, this approach associates stations to the least loaded APs to minimize channel occupancy, improving the aggregated throughput of the network. The association process is triggered whenever an AP is over a dynamic load threshold. Then, stations are reassociated by seeking the AP whose channel is least loaded.

Wi-Balance works in two distinct phases. Firstly, channels are assigned by minimizing collision domains. For each AP, the algorithm assigns a channel that has not been assigned yet to any of its neighbours. If there are no more channels available, the one with the smallest number of neighbours assigned is selected. Once all the APs have a channel assigned to them, these channels are fixed and the second phase starts. In this phase, the algorithm balances the load across all the APs assuming that there are no collision domains. Load balancing at the AP level effectively improves network performance when collision domains are minimized. To do so, the algorithm establishes an AP load threshold that takes the average load as a reference. If any AP is over the threshold, a reassociation process is triggered for the AP which was over the threshold. This process tries to associate the stations by minimizing the product between the current occupancy ratio and the perceived signal strength.

B. Wi-Balance Issues

Despite Wi-Balance being an improvement upon RSSI-based approaches, we think there is still room for further enhancements. First, channels are assigned by minimizing collision domains. However, once this assignation takes place, channels are never reassigned, i.e., the assignation is static. This could be a problem as collision domains are sometimes unavoidable due to the low number of available channels. After that, the algorithm balances the load across all the APs while assuming that there are no collision domains, even though this assumption may be incorrect. Furthermore, the threshold that triggers this load balancing procedure does not adapt to the network's load level. This might produce an excessive number of handovers with low load levels.

Load balancing at the AP level has been shown to improve network performance when collision domains are minimized [1]. However, in the case of unavoidable collision domains, the stations associated with the APs that share the same channel will be affected by the traffic of both APs, so the channels could become a bottleneck. Moreover, Wi-Balance does not consider the average signal strength of all the stations in the network and does not reassociate upon a deterioration in signal quality. Thus, even if a user redistribution process could result in a better load balance, the average signal strength could deteriorate. This would lead to the number of retransmissions and the Modulation and Coding Scheme (MCS) keeping the channel busy for more time and wasting resources.

C. Proposed Enhancements

This work aims to mitigate the said problems associated with Wi-Balance. To do so, the main contributions of our approach are: (i) the adjustment in the AP load thresold that was already in use in Wi-Balance; and (ii) the introduction of two new indicators that trigger the reassociation of stations. The SDN-controller gathers the uplink RSSI and channel usage for each AP in bytes. Furthermore, it computes total channel occupancy, i.e., the sum of the channel usage for all the APs using the same channel. Thus, by using these metrics, three indicators that trigger user reassociation or channel reassignation processes are defined:

- *Indicator 1 - Average RSSI of an AP*: This indicator aims to avoid the use of low MCSs, which provide robust signals but low datarates as a consequence of a poor signal strength. The average RSSI of an AP refers to the average of the uplink RSSIs of all the stations connected to that AP. Fig. 1 shows a scenario where this indicator triggers a reassociation process. In this scenario, the subtraction of the average RSSI of AP2 (the minimum) from the average RSSI of AP1 (the maximum) is bigger than the median and thus, possible handovers are studied.
- *Indicator 2 - AP load*: This indicator was already present in Wi-Balance. However, the threshold that activated it has been changed to use only network metrics, while Wi-Balance used external values. Fig. 2 shows a handover as the subtraction of the minimum load (AP3) from the maximum load (AP2) is bigger than the median load (AP1).
- *Indicator 3 - Channel Occupancy*: This indicator aims to improve the performance of the network when there is more than one AP in the same collision domain. It is designed to avoid overloaded channels. Fig. 3 shows a scenario where this indicator triggers a channel reassignation as the subtraction of the channel occupancy of Channel Y (the minimum) from the channel occupancy of Channel X (the maximum) is bigger than the median.

The role of the different indicators in the user association algorithm and how they trigger the reassociation and channel reassignation processes is shown in Algorithm 1, where each one is represented by an `if` statement. It is executed periodically, in a configurable period of time, whenever the controller receives an update of the metrics for any AP. On the controller side, our solution mantains, for each indicator, the results reported by each AP. Based on this data, when for any indicator the condition `Max - Min` > `Med` is fulfilled, the trigger is activated. Note that the statistical functions (i.e.,

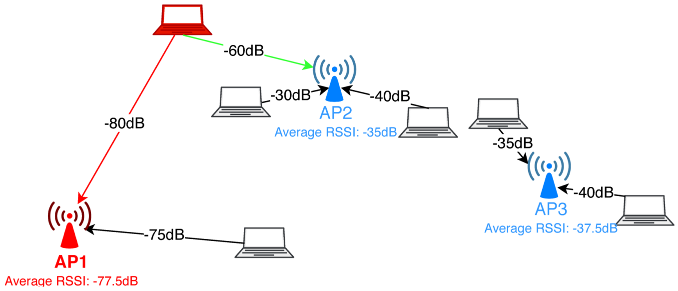

Fig. 1: *Average RSSI* indicator triggering a handover as condition (`Max(AvRSSIs)` - `Min(AvRSSIs)`) $>$ `Med(AvRSSIs)` is met ($77.5 - 35 > 37.5$).

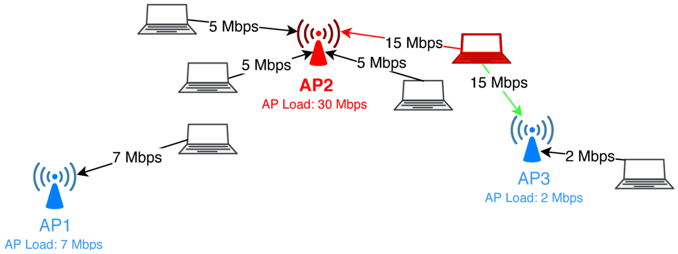

Fig. 2: *AP Load* indicator triggering a handover as condition (`Max(APLoads)` - `Min(APLoads)`) $>$ `Med(APLoads)` is met ($30 - 2 > 7$).

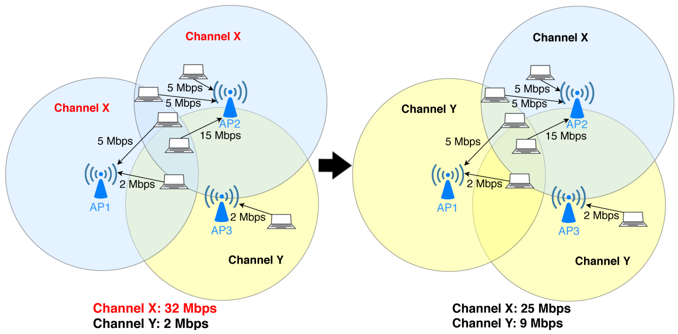

Fig. 3: *Channel Occupancy* indicator triggering a channel reassignation as condition `Max(ChOccup)` - `Min(ChOccup)` $>$ `Med(ChOccup)` is met ($32 - 2 > 17$).

maximum, minimum and median) are calculated by taking into account the values reported by all the APs for a specific indicator during a configurable period of time. This design choice contributes to reducing the ping-pong effect and to ensuring a fairer resource utilization. If AP load or average RSSI triggers are activated, the SDN-controller will seek the AP-station associations that can improve the performance. For this purpose, for each station it checks which association maximizes the value of $\texttt{RSSI}_j \times (\texttt{ChLoad}_{AP_i} + \texttt{LoadAP}_i)$, where j refers to the station and i to the AP. By maximizing the product the algorithm selects the best trade-off between signal quality and the network resources used. A good average signal quality helps to select a higher MCS, which results in a reduction in the time taken by each frame to be transmitted and in an improvement in performance. Having more loaded channels (`ChLoad`) and APs (`LoadAP`) will also make the value of the product smaller. We remind the reader that RSSI is always a negative value. Thus, maximizing the product seeks the best trade-off between signal strength, channel load and AP load. If there is no better option, the algorithm selects the same AP and no action will be performed.

```
Algorithm 1 User association algorithm
Input:
  AvRSSIs: list of average RSSI of each AP.
  APLoads: list of the channel occupancy of each AP.
  ChOccup: list of the channel occupancy of each channel.
Output:
  NewAP: target AP to which perform a user handover.
if Max(APLoads)-Min(APLoads)>Med(APLoads) then
  for each i in APs do
    for each j in $\texttt{stationsAP}_i$ do
      newAP ← $\text{Max}_j(\texttt{AvRSSIs}_j \times (\texttt{ChLoad}_{AP_i} + \texttt{LoadAP}_i))$
else if Max(AvRSSIs)-Min(AvRSSIs)>Med(AvRSSIs) then
  for each i in APs do
    for each j in $\texttt{stationsAP}_i$ do
      newAP ← $\text{Max}_j(\texttt{AvRSSIs}_j \times (\texttt{ChLoad}_{AP_i}+\texttt{LoadAP}_i))$
else if Max(ChOccup)-Min(ChOccup)>Med(ChOccup) then
  ChannelReassignation()
```

Our approach must also rely on a channel assignment algorithm. For this purpose, as a basis we take the algorithm presented in Wi-Balance, which recursively assigns a channel to the set of APs with the lowest number of available channels, i.e., channels that have not been assigned yet to neighbour APs and do not overlap with the ones already assigned to them. If any channel is available, the algorithm chooses the least used one to reduce interference. This algorithm, as it is in Wi-Balance, is run once at the beginning to establish an initial assignment in the network. However, as mentioned in the previous subsection, the assignment carried out in Wi-Balance is never again reconfigured to adapt to the changing network conditions. In this work, in addition to the initial assignment, the algorithm is also exectued when the *Channel Occupancy* indicator exceeds its threshold, i.e., when the channel utilization is not even and the problem cannot be solved just by calculating a new user-AP association. The algorithm behaves in the same manner. However, if a channel's *Channel Occupancy* is over the threshold, it is not considered as a possible channel. A channel is over the threshold if it is the most loaded one and the condition `Max(ChOccup)` - `Min(ChOccup)` $>$ `Med(ChOccup)` is true. The use of the former algorithm (i.e., without introducing this improvement) after the initial assignment would result in a situation where, although the collision domains would be minimized, the load distribution across channels would still be uneven, as the current user association would be mantained regardless of this change. In this manner, collision domains may not be minimal but having N access points with low load in the same collision domain performs better than having an overloaded channel.

D. Reference Architecture

The proposed scheme was implemented by taking the 5G-EmPOWER platform [22], [23] as a reference. 5G-EmPOWER is an open Mobile Network Operating System (MNOS) which combines SDN and Network Function Virtualization (NFV) in a single platform that supports lightweight virtualization and heterogeneous radio access technologies including Wi-Fi and LTE. It builds upon a set of high-level APIs providing developers with full visibility of the network state and allowing them to deploy network services and fast prototyping of novel services and applications at the application layer. The state information is kept all over the network infrastructure in a distributed way. As a result, the network works as in its last known state even if the controller is unavailable.

One of the main advantages of leveraging an SDN-based architecture is the ease with which the required network metrics information can be acquired and its greater availability. The solution presented in this paper is introduced at the application layer in the form of a network application. As a result, given its privileged position sitting on top of the SDN-controller, such a solution is able to obtain the network status in real-time (through the northbound interface) in order to make more accurate management decisions. Periodically, with a configurable frequency on the controller side, the APs report the network status to the controller. Such reports contain information about the channel occupancy, the clients, and the status of the channel, among other data [23]. Even though these metrics are periodic, they are not used immediately as our solution uses the average of each one of these values. This is done to avoid ping-pong effects as the traffic might be bursty, which may trigger a handover that has to be reverted in a short period of time. In this paper, our approach is applied to the uplink transmissions. However, by using IEEE 802.11k [24] downlink transmissions would work in the same way, although not many devices support this standard apart from some Apple ones [25], and its study is left for future work.

Furthermore, an additional advantage provided by 5G-EmPOWER is the Light Virtual Access Point (LVAP) abstraction, which facilitates state management of wireless stations through a high-level interface. Each station has its own individual and unique LVAP. This concept allows seamless handovers between APs even when they operate on different channels through the use of the Channel Switch Announcement (CSA) defined in the IEEE 802.11 standard. Thanks to the use of a specific Basic Service Set Identifier (BSSID) per LVAP (i.e., per user), beacons and CSA frames are delivered in unicast mode to each user, which makes it possible to maintain both authentication and association active even upon a handover between 2 APs. Thus, if a handover is needed, the LVAP is instantiated at the target AP and remains inactive until the station connects to the new AP. When this procedure finishes, the source LVAP is removed. This feature represents a key requirement for our solution since it enables seamless handovers, which is essential to keep the performance and simplifies infrastructure management after reconfiguration and reassociation decisions.

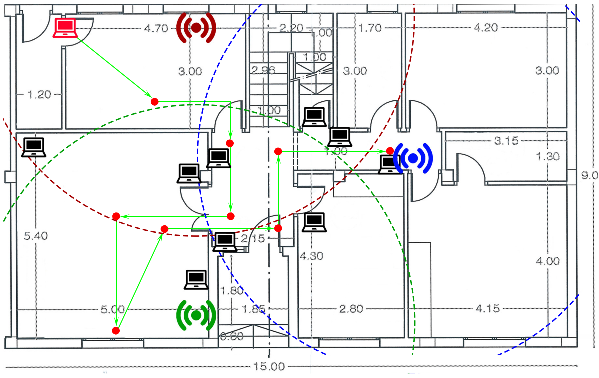

Fig. 4: Layout of the deployment used for the evaluation including the location of users and APs.

IV. PERFORMANCE EVALUATION

A. Evaluation Methodology

The evaluation was performed experimentally on a testbed made of three APs, whose location can be seen in Fig. 4. These locations were chosen to spread the coverage area in a realistic manner, while keeping overlapping ranges. The APs are built on PCEngines ALIX 2D boards equipped with a single Atheros AR9220 Wireless Network Interface Controller (NIC) set to use IEEE 802.11n and the 2.4 GHz band. They were flashed with version 17.01 of EmPOWER-LEDE, an open-source Linux distribution based on OpenWRT [26]. They were tuned to channels 1, 6 and 11 on the first iteration of the channel assignment algorithm. The tests were carried out in an area where no external interference is present in these frequency bands in order to ensure that any result obtained strictly corresponds to the behavior of the network under study. A Linux computer running the 5G-EmPOWER controller is connected to the APs in a star topology. Three computers working as monitors register all the Wi-Fi headers in the medium to analyze the performance indicators that are described in the next section. Each monitor is tuned to listen to the same channel as one of the APs.

We used a total of 10 Wi-Fi clients, which share the radio resources available in the network. One mobile station and nine static ones make up the set of clients. The static stations are Raspberry Pi 3 B running Raspbian Stretch. They are placed so that they are in range of all the APs to generate a greater level of interference as well as a higher number of possible user-AP association combinations and channel assignments with the aim of thoroughly testing the algorithm. The moving station is a Toshiba laptop powered by an Intel Atom processor and with 4 GB of RAM running Ubuntu 18.04.

Nine experiments named from A to I were carried out comparing our approach with Wi-Balance and RSSI-based approaches using uplink traffic. These transmissions take place between all the stations and the server located in the controller, i.e., all the APs share the same server. In each test, the moving

TABLE I: Data gathering cases.

Test	Traffic	Traffic distribution	Bitrate (Mbps)
A	UDP	Constant - Constant	5
B	UDP	Constant - Constant	10
C	TCP	Constant - Constant	-
D	UDP	Constant - Intermittent	5
E	UDP	Constant - Intermittent	10
F	TCP	Constant - Intermittent	-
G	UDP	Intermittent - Constant	5
H	UDP	Intermittent - Constant	10
I	TCP	Intermittent - Constant	-

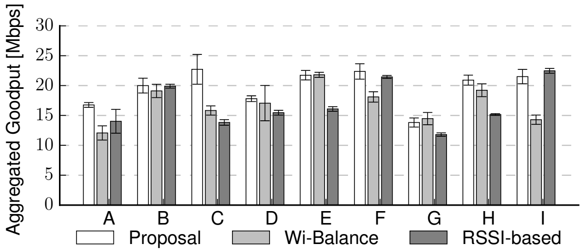

Fig. 5: Network-wide aggregated goodput.

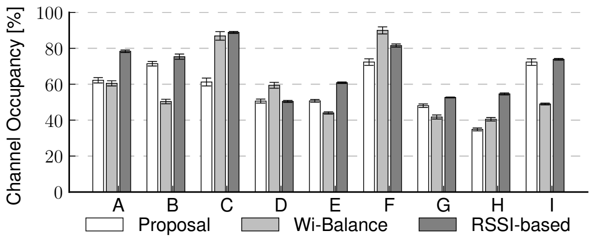

Fig. 6: Network-wide channel occupancy.

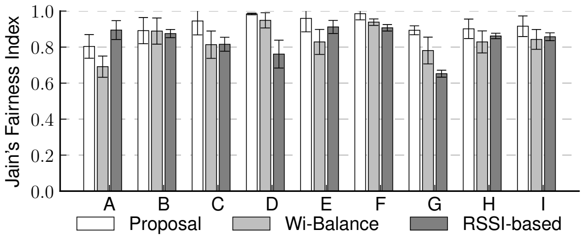

Fig. 7: Jain's Fairness Index of stations goodput.

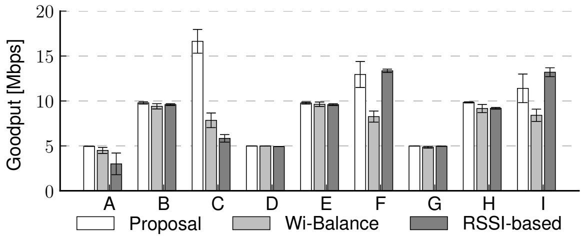

Fig. 8: Goodput of the moving station.

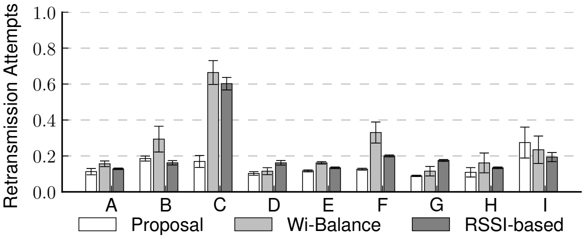

Fig. 9: Retransmissions per packet of the moving station.

station constantly generates traffic while completing the path depicted in Fig. 4 in 2 minutes. Each section of the path is walked in 5 seconds while stopping for 10 seconds at the red dots. In the case of the static stations, they are divided into two groups. The first group transmits during the whole duration of the test. The second group sends data to the AP for 30 seconds, then stops for 30 seconds, and repeats. The role of both groups is then switched. This is done to avoid any possible negative effect produced by the distribution of the clients. In addition, there are tests in which both groups transmit constantly, as shown in Table I. In order to obtain representative data, each test is repeated 5 times to calculate their average. Both UDP and TCP transmissions are carried out. For UDP two bitrates are selected, while TCP transmissions obtain an adaptive bandwidth using the sliding window algorithm. In this way, we aim to assess how the different approaches perform with different bandwidth requirements from the stations.

B. Experimental Results

Fig. 5 shows the network-wide aggregated goodput achieved by the three studied schemes. The figure clearly shows how the proposed scheme substantially improves upon the results of Wi-Balance and the RSSI-based schemes. Our approach is, on average, 20% better than Wi-Balance and up to 50% better in the best case. It also shows that our solution outperforms the RSSI-based approach by 22% on average and up to 60% in the best case. This improvement is achieved by combining the three indicators used in our scheme: *AP load*, *Channel Occupancy* and *Average RSSI of an AP*. In the case of channel occupancy, as shown in Fig. 6, our approach obtains the same level as Wi-Balance while outperforming RSSI-based approaches by 10%. In addition to improving network aggregated goodput, an efficient client association algorithm must allocate the network resources fairly for all the devices. Our proposal achieves a fairer resource allocation, as shown by Jain's Fairness Index in Fig. 7. In fact, it outperforms Wi-Balance by 10% and the RSSI-based approach by 11%. Moreover, it is up to 16% better than Wi-Balance and up to 30% better than the RSSI-based approach.

One of the main improvements of our approach with regard to Wi-Balance is the adaptation to perceived signal strength thanks to the use of the *Average RSSI* indicator. To show this effect, Fig. 8 and Fig. 9 show the performance of the mobile station. In this case, the movement of this station clearly results in greater variation in terms of RSSI with respect to the static ones. In particular, when looking at the goodput of the moving station it can be observed that our approach outperforms both Wi-Balance and RSSI-based association once again, as shown in Fig. 8. Our approach performs 25% better than Wi-Balance and 27% better than the RSSI-based approach. The number of retransmissions per packet of our approach is 30% lower than Wi-Balance and 20% lower than the RSSI-based approach, as shown in Fig. 9. Such a big improvement is a consequence of the introduction of the *Average RSSI of an AP* indicator. Due to the absence of this threshold in Wi-Balance, on some occasions the RSSI-based approach actually presents better results than Wi-Balance.

In light of these results, it seems clear that our approach offers better performance when it comes to resource allocation. Taking more factores into account makes it more versatile and allows it to overcome the various issues not considered in Wi-Balance, despite the fact that this scheme already improved upon the traditional RSSI-based approaches, as mentioned. The fact that Wi-Balance does not take average signal strength into account might produce the general use of lower MCSs, which results in a lower level of performance of the network since the negative effect of having a lower signal strength may have a bigger impact than the improvement resulting from a lower channel occupancy.

The fact that Wi-Balance does not take signal strength into account can have the contrary effect when carrying out the association. Worse signal quality may have a bigger impact than the improvement in the load balancing.

V. CONCLUSION

In this paper, we have presented an enhanced user association scheme that addresses the main problems identified by previous works. To make this possible, our solution identifies unbalanced resource allocation situations and migrates stations to other APs in order to find the optimal trade-off between signal quality, channel load and AP load. The proposal maintains a good average RSSI to avoid the problems derived from the use of MCSs with low data rates. The network traffic is distributed by combining a channel assignment solution with load balancing techniques at both channel and AP levels.

The performance of our approach has been assessed on a real-world testbed in different scenarios, considering both mobile and static users. By means of this evaluation it has been demonstrated how our solution clearly outperforms other state-of-the-art schemes, such as Wi-Balance, by an average of 20%, improving network fairness by 10%. Moreover, it also outperforms the RSSI-based approach by 22%. Thus, we can conclude that our algorithm can offer better load balancing which means better network performance.

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