Smart Access Point Selection for Dense WLANs: A Use-Case

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***Abstract*— This paper addresses the problem of Access Point (AP) selection in large scale IEEE 802.11 Wireless Local Area Networks (WLANs) through the study of a shopping mall use-case. We investigate through simulations the impact of a smart AP association algorithm including two strategies based on the Fittingness Factor (FF) concept, which considers the suitability of the requirements for different stations accessing the network, on the performance of the WLAN studied in this use-case. The proposed AP selection algorithm is implemented in a framework based on Software Defined Network (SDN), which handles the APs distributed in the WLAN of the considered shopping mall use-case. The simulation campaign illustrates the important gains, both in terms of users' satisfaction and assigned throughput compared against the AP selection suggested by the IEEE 802.11 standards. Moreover, this result gives to the service providers a trade-off between efficiency and complexity delivered by the proposed strategies included in our smart AP selection algorithm when the SDN framework is used to manage large WLANs.**

Keywords*— *Large scale WLAN; AP selection; Fittingness factor; Potential game; Software Defined Network.

I. Introduction

Wi-Fi technology is now almost ubiquitously available and has made its way beyond the home and work place into public spaces such as airports, train stations, shopping malls and university campuses. These large scale IEEE 802.11 Wireless Local Area Networks (WLANs) are built by deploying Radio Frequency (RF) overlapping IEEE 802.11 Access Points (APs), in order to guarantee good signal coverage and redundant connectivity to users. The traffic within these networks is characterized by heterogeneous Quality of Service (QoS) demands and different transmission rates, as each wireless user might be running a different application. Moreover, these demands are increasing over time as more bandwidth-hungry services are introduced. However, since the Wi-Fi spectrum is a finite resource, a significant increase in wireless traffic will ultimately result in congestion within the network, affecting the overall quality of coverage, and reducing the overall performance. Therefore, it is paramount to devise an AP selection approach that reflects the constraints of these large scale WLANs and the QoS requirements of wireless users.

Guided by this motivation, in this paper we address the problem of AP selection in large scale WLANs through the study of a shopping mall use-case located in Paphos, Cyprus. The shopping mall consists of two floors where Wi-Fi coverage is provided by a number of APs uniformly deployed within the building. The APs composing the WLAN have been designed to reach high capacities through, for instance, automatic interference mitigation and transmit beamforming, which are crucial to increase the capacity provided to the customers in high-density environments. On the other hand, the current design does not consider a smart allocation of the APs among the customers taking into account their QoS demands that might exploit better the potentiality of these APs.

In this context, our study investigates the performance of the WLAN located in the shopping mall use-case through simulations to expose the limitations of the conventional AP selection approach with regards to wireless users' satisfaction and the capacity of the networks. Specifically, we propose a smart AP association algorithm that addresses QoS requirements using the Fittingness Factor (FF) concept, which is a well-known tool used in the literature to compute the suitability of a wireless user application with spectrum resources [1]. Our previous results in [2] and [3] showed that it yields better performance than other solutions found in the literature that proposed AP selection strategies [4]-[6]. Therefore, in this paper we present a smart AP selection algorithm that includes two approaches based on the FF, which represents an efficient tool to address this problem compared to other methods found in the state of the art. The first approach is based on the so-called *Network Fittingness Factor* that we have proposed and assessed in [2] and [3], and the second one is based on a centralized *Potential Game* [7], which will be explained throughout the paper.

With respect to our previous work, in this paper we also strengthen our smart AP selection algorithm through the inclusion of a new module in a framework based on the Software Defined Network (SDN) architecture designed and implemented in the context of the H2020 Wi-5 (*What to do With the Wi-Fi Wild West*) project [8]. This module is able to make use of a statistical characterization of the throughputs required for applications experienced by actual Wi-Fi customers of the shopping mall and then, to provide realistic QoS requirements used for the computation of the FF. Hence, we also exploit the use-case to further validate our work through real-life monitoring data related to users' QoS requirements, which has not been used in our previous work.

Therefore, the new contributions of our paper can be summarized as follows:

- We developed a framework for smart AP selection algorithm in a WLAN of a shopping mall use-case

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based on SDN to efficiently exploit the potentiality of the APs in terms of capacity. Moreover, the flexibility of SDN [9]-[11] allowed to implement two smart AP selection strategies in the algorithm based on the *Network Fittingness Factor* and the *Potential Game* in the central controller able to handle the APs located in the considered use-case. As we will explain throughout the paper, this approach will enable the service provider to select its most preferable strategy.

- We designed and implemented a novel module that provides a statistical characterization of the radio environment based on real-time measurements, which allows a realistic computation of the FF included in the smart AP selection algorithm.

The rest of the paper is organized as follows. In Section II, we provide a detailed description of the use-case studied in this paper, together with the problem formulation including the use of the FF and our SDN-based framework to manage large WLANs. In Section III, we present the analytical details of our AP selection algorithm based on the use of the FF. Section IV provides the details of the smart AP selection algorithm proposed in this paper. In Section V we evaluate the performance results obtained using our AP selection approach for the shopping mall use-case. Finally, in Section VI we present our conclusions and future works.

II. Use-Case and Problem Formulation

The use-case considered in this work is the Kings Avenue mall, which is the biggest shopping mall in Cyprus and is located in the city of Paphos. The building covers an area of 103,000 m^2 including basements and a parking with a capacity of 1250 vehicles. A large WLAN is deployed to provide Wi-Fi connectivity in an area of approximately 41,000 m^2 distributed in the two floors illustrated in Figure 1. The WLAN consists of 7 IEEE 802.11n/ac APs, deployed at a distance of approximately 33 meters from each other. Moreover, the APs are located on the roof of the first floor and their distribution is illustrated in Figure 1(a). These APs could provide a theoretical capacity up to 450 Mbps and 1300 Mbps, in 2.4 GHz and 5 GHz, respectively.

A key functionality of the proposed smart allocation of the APs is the inclusion of realistic QoS demands of the Kings Avenue mall customers. Hence, the downlink bit rate requirements in terms of throughput were monitored through NetFlow software for a set of more than 4000 customers connecting to the WLAN during the whole month of June 2017. This analysis then provided a realistic statistical characterization of the expected throughputs required for downlink applications experienced by actual Wi-Fi customers, and used in our smart AP selection algorithm. In detail, the customers during the analysed month have experienced applications requiring on average approximately 111 kbps throughputs bit rates with pick values of around 1.1 Mbps.

Figure 2 illustrates the Cumulative Distribution Function (CDF) of these throughputs bit rates. Specifically, the horizontal axis represents the domain of the throughput values required by the customers during the analysed month, while the vertical axis is their probability to be required. The use of this CDF in the algorithm will be clarified in Section IV.

(a) First Floor

(b) Ground Floor

Figure 1. Floorplans of the Kings Avenue mall

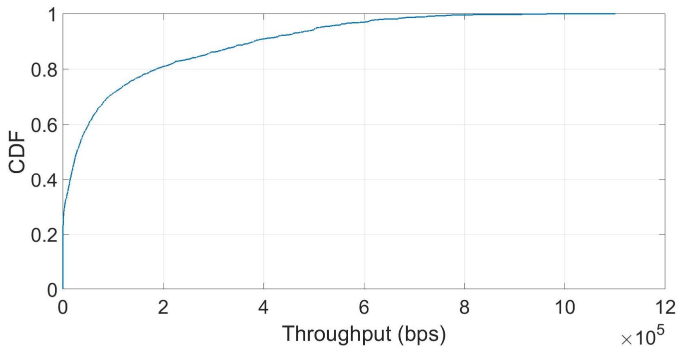

Figure 2. CDF of required throughputs bit rates

A. Problem Formulation Using the Fittingness Factor

To better formulate the problem of AP association in WLANs, we consider N as the set of APs in the network and M as the set of downlink traffics of the wireless users, where $|N| = n$ and $|M| = m$. Note that in our model, an application experienced by each wireless user is called *flow*, while each application connected to the network is defined as *active flow*. Accordingly, the problem of finding a suitable AP $i \in N$ to serve an active flow $j \in M$, is based on the Fittingness Factor (FF) metric. Specifically, the FF is a parameter with its value between 0, which corresponds to the lowest suitability and 1 that corresponds to the highest suitability [1]-[3].

The suitability of an AP i to serve a flow j represented by the FF takes into account the data bit rate that the flow j requires, $R_{req,j}$, and the data bit rate that the AP i can deliver, $R_{i,j}$. Therefore, the FF for AP i and flow j, $f_{i,j}$, can be formulated as the following function ϕ:

$$\phi(R_{i,j}, R_{req,j}) = f_{i,j} \in \mathbb{R} \mid 0 \leq f_{i,j} \leq 1 \quad (1)$$

$R_{i,j}$ is defined through the Shannon–Hartley theorem as the following function g of all these parameters and explained in [3]:

$$R_{i,j} = g\left(\psi_{i,j}, BW_i, A_i, C_i\right) \quad (2)$$

Where $\psi_{i,j}$ denotes Signal to Interference plus Noise Ratio (SINR) experienced by flow j when allocated to AP i; BW_i denotes the bandwidth assigned to AP i in Hz; A_i denotes the number of all the flows connected to AP i; C_i denotes the maximum capacity served by AP i in bits per second (bps).

The problem formulation expressed in (1) requires a management system able to monitor the WLAN' APs and identify the requirements of active flows. In the next subsection, we present a framework based on SDN to manage large WLANs, where the controller is able to monitor the status of the network and detect requirements of active flows.

B. *SDN-based Framework*

In our work, we consider that the WLAN located in the shopping mall use-case is controlled via the SDN-based framework illustrated in Figure 3 previously proposed in [3] and strengthened through the inclusion of the new module called *Required Bit Rate Management* explained below. In this framework, the AP selection algorithm runs on top of the SDN controller, which manages the APs. According to this architecture, the controller is able to take regular measurements from the network, monitoring the characteristics of new flows entering the network, provide a statistical characterization of the radio environment dynamics, and connecting the flows to their most suitable AP. For that, our SDN framework relies on the following modules:

- *Available Bit Rate Module*, which provides the bit rate that each AP in the shopping mall can achieve for a new flow connection, measured at the physical layer, and explained in the previous subsection.
- *Required Bit Rate Management Module*, which includes the *Required Bit Rate* and the *Knowledge Database*. The *Required Bit Rate* provides the QoS requirements of the flow requesting connection based on a statistical characterization of the required throughputs of the applications experienced by the customers of the Kings Avenue mall. The details of how this information is gathered are provided in Section IV. The *Knowledge Database* stores the values of the CDF that characterizes the required throughputs measured in real-time illustrated in Figure 2, and provided to the *Required Bit Rate* when required. Moreover, it stores the required bit rates and the available bit rates of all the active flows, and the most recently computed network utility function U needed for the AP selection approach based on a *Potential Game* as it will be explained in the next section.
- *Decision Making Module*, which is triggered every time a new flow needs to be associated to an AP. It first collects the available information from the *Required Bit Rate*, *Available Bit Rate* and *Knowledge Database* modules, i.e., QoS requirement of the new flow, bit rate available in each AP for the new flow, required bit rates and available bit rates of all the active flows, and the network utility function U in the case of *Potential Game*-based approach. Then, it uses this information to assign to each active flow in the network the most suitable AP based on the proposed algorithm.

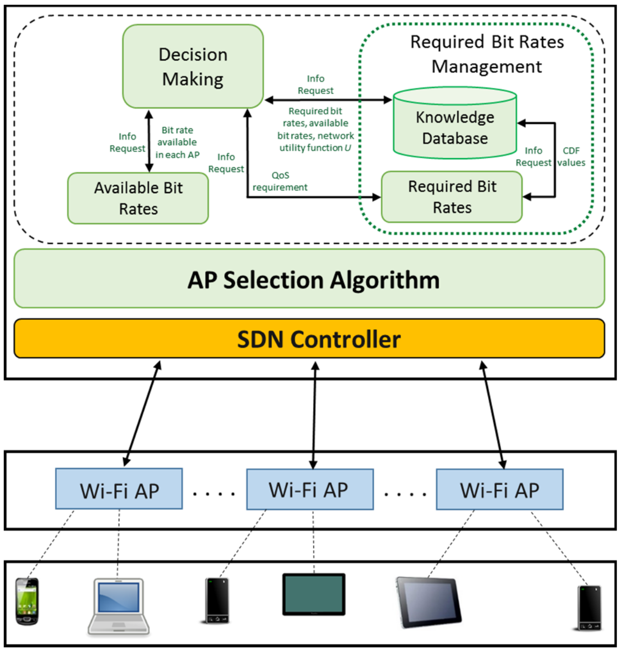

Figure 3. SDN-based Framework implementing smart AP selection

III. Solving the AP Selection Problem Exploiting Fittingness Factor

To solve the AP selection problem formulated in (1), we defined in [2] and [3] a parameter called *Network Fittingness Factor* (net_f). The *Network Fittingness Factor* relies on the *Standard Deviation Function* (σ) which defines the variation in terms of the average FF that might result when an AP i starts serving a new flow j. In detail, for each AP i, the available bit rate served to each active flow is recomputed through (2) by considering the effect caused by the connection of new flow j. Based on the new values of the bit rates, the FFs of the active flows are then updated through (1). Finally, the standard deviation is calculated as follows:

$$\sigma_{i,j} = \sqrt{\frac{\sum_{k=1}^{K}\left(f_{k,i}-\bar{f_i}\right)^2}{K}} \; where \; \bar{f_i} = \frac{1}{K}\sum_{k=1}^{K} f_{k,i} \quad (3)$$

In (3) K represents the number of all active flows in AP i, which includes both the previous flows active in the AP with their FFs updated, and the new flow j. Given that there are N APs available for selection to serve the new flow j, the *Network Fittingness Factor* is used to optimise the following parameters: (i) the FF of the AP serving the new data flow, and (ii) the standard deviation factor that maintains the overall network performance as much as possible, in order to determine the most suitable AP. This optimisation is solved through the computation of net_f for the new flow j and is formulated below:

$$net_{f_j} = arg\,max_{i\in\{1,\dots,N\}}\left\{F_{i,j}\right\} \quad (4)$$
$$where \; F_{i,j} = f_{i,j}\left(1-\sigma_{i,j}\right)$$

Hence, net_{f_j} computed through (4) aims to optimise the individual performance of the new flow to the associated AP by maximizing its FF, while trying to safeguard the overall network performance by minimizing the impact on the other active flows through the standard deviation. Note that for an AP with no other active flows, its standard deviation value is 0.

The obtained results in our work based on the *Network Fittingness Factor* [2] and [3] showed that the performance could be further improved especially in crowed environments, where the number of users that could not be satisfied grows bigger as the total users increase. Therefore, we claim that the use of the FF could be better exploited introducing a possible reallocation of the APs to the flows connected to the network when required. For this reason, we consider the *Potential Game*, which allows a more efficient distribution of the wireless users among the APs of the considered network. Note that potential games perform a distributed optimization of resource allocation through the convergence to a Nash Equilibrium (NE), which is always guaranteed [12]. However, such implementation will be very complex, as each player needs overall information about the remaining players of the network, making the solution not scalable. Therefore, the use of SDN allows to play the game at the central controller reducing the implementation complexity.

Hence, for each new flow trying to connect to the network, the controller plays a potential game for all the active flows in the WLAN located in the shopping mall use-case to find the optimised AP allocation for all of them. Specifically, in order to optimise the distribution of the m flows to be served by the n APs of the network, we consider the network utility function U as the log-sum of the FFs of all the m flows connected to the network. We therefore aim to optimise, through U, the sum of the logarithms of the FFs provided by the APs allocated to each flow j connected to its corresponding AP, AP_j, in order to guarantee a proportional fairness in the AP allocations. On the other hand, in the considered scenario, any flow might achieve an FF value equal to zero. Therefore, in order to avoid a possible inclusion of zero in the logarithm argument, we consider a modified version of the objective function, with the sum of the logarithms of the FFs plus one [12].

Therefore, U to be optimised can be defined as follows:

$$U = \sum_{j=1}^{m} \log(f_{j,AP_j} + 1) \quad (5)$$

With this definition, it can be demonstrated that if the controller improves the utility function for only one player, i.e., one flow, given the most recent action made for the other players, i.e., other flows, then the process will always converge in finite steps to a NE [12]. The NE is found when the controller does not further improve the utility U. The analytical details of the centralized potential game and the converged NE implemented in our AP selection strategy are out of the scope of this paper and can be found in [12]. Note that the optimisation of U results in a possible handover of the flows towards new APs when needed. However, it has been demonstrated that in SDN-based networks, seamless inter-AP handovers can be applied without a harmful loss of connection [13].

IV. SMART AP SELECTION ALGORITHM

The objective of this algorithm is to find the most suitable AP for all the flows connected to the Wi-Fi network provided in the Kings Avenue mall each time a customer requires connection for a new flow j. Algorithm 1 illustrates in detail the sequence of steps implemented in the controller during the execution. As depicted in Figure 3, the *Decision Making* module implemented in the controller needs to acquire all the information used in the AP selection algorithm from *Required Bit Rate*, *Available Bit Rates* and *Knowledge Database* modules. Therefore, first, the *Decision Making* module acquires the QoS requirements of the new flow j in terms of throughput generated in the *Required Bit Rate Management* for computation of the FF illustrated by equation (1) (line 1). Specifically, for each new flow connection, the QoS requirement is generated within the *Required Bit Rate Management* by the *Required Bit Rate* module from the CDF illustrated in Figure 2 acquired by the *Knowledge Database*, through the *inverse transform sampling* method. This method represents a classical approach to generate pseudo-random samples from a probability distribution, such as a CDF [14]. In detail, let X be the set of throughputs whose distribution is described by the CDF here named F, the *inverse transform sampling* method is applied as follows:

- For each new simulated flow j the *Required Bit Rate* module generates a random number a from the standard uniform distribution in the interval [0, 1], which represents a pseudo-random sample transformed by the CDF F to a realistic throughput required by a customer.
- It then, computes the value $x \in X$ such that $F(x) = a$.
- It finally sends x to the *Decision Making* module as the QoS requirement of flow j from the distribution described by F.

Algorithm 1 – Smart AP Selection

1: **get** requirements from *Required Bit Rate*
2: **get** availability from *Available Bit Rate*
3: **get** information stored in *Knowledge Database*
4: **run** AP selection strategy
5: **apply** configuration
6: **update** *Knowledge Database*

Then, the *Decision Making* module collects from the *Available Bit Rates* module all the link capacities in terms of the bit rate, that each AP i can provide to the new flow j and computed using (2) (line 2). Further details on this computation can be found in [3]. Hence, the *Decision Making* module gets the information stored in the *Knowledge Database* related to all the other flows already active in the network, i.e., the bit rate requirements and the available bit rates based on (2), and the most recent computed network utility U in case of *Potential Game*-based approach (line 3). Afterwards, the *Decision Making* module can run one of the strategies introduced in the previous section based on the FF (line 4).

In detail, in case of a strategy based on the *Network Fittingness Factor*, for each AP i, the *Decision Making* module uses all the acquired information to: first compute the updated bit rates available to serve the existing active flows in AP i using (2) considering the effect caused by a possible connection of new flow j; second use the bit rate requirements of all the flows connected to AP i, and compute the *Standard Deviation Function* ($\sigma_{i,j}$) for AP i through (3); third select the most suitable AP for flow j based on the net_{f_j} in (4). Let *m* be the number of all the active flows in the network at a certain time instant *t*, the time complexity of this strategy included in the AP selection algorithm is linearly related to the number of flows and we can define its approximation as *O(m)* [3].

While in the case of a strategy based on the *Potential Game*, the *Decision Making* module uses all the acquired information to execute a sequential game with round robin scheduling to find the optimized value of *U* through (5) until the pure NE is found. Specifically, in each round, for each flow *j* connected to the network and for each AP *i* covering the area in which flow *j* takes place, it first updates all the FFs of the flows affected by the connection of flow j in AP i using (1) and second it computes *U* that needs to be optimized through (5), including such updated FFs, f_{j,AP_j}. Given *R* (the number of rounds needed to reach the NE), *m* (the number of flows active at certain time) and *W* (the number of APs available on average for a new flow), the complexity of this strategy included in the AP selection algorithm is linearly related to *m* and expressed as *O(RWm).*

Finally, in both strategies the *Decision Making* module stores the required bit rate and the available bit rate of the last flow connected to the network in the *Knowledge Database* that will be used during the next execution of the algorithm (line 6).

Note that the flexibility of SDN allows the implementation of both strategies on top of the controller that handles the APs composing the WLAN of the King Avenue mall. As we will explain in the next section, in case of high load in the APs, the service provider will be able to select the preferred strategy based on a trade-off between performance and complexity.

V. USE-CASE MODELLING AND PERFORMANCE EVALUATION

To evaluate the performance of our AP selection algorithm, we modelled the first floor of the King Avenue mall illustrated in Figure 1(a) using MATLAB. In this model, we consider the SDN controller that manages this section of the WLAN as previously described in Section II.B. Specifically, we have simulated the area of 230m×90m representing the first floor and covered by 7 802.11n APs. Moreover, for this evaluation we have considered the path loss based on the ITU model for commercial areas in buildings [15]. The values of BW_i and C_i needed in eq. (2), i.e., AP's bandwidth and AP's maximum reachable capacity, and the AP's transmit power are set for all the APs as 20 MHz, 450 Mbps, and 20 dBm, respectively.

To model the data traffic of wireless users inside the shopping mall, we simulated a set of *m* active flows, where $1 \leq m \leq 2000$ in order to represent a realistic number of customers in rush hours. The QoS requirements of these flows follow the CDF presented in Figure 2, and are generated using the *inverse transform sampling* method as explained in Section IV.

A. Performance Evaluation

We use the simulation model of the King Avenue mall and the users traffics described above to assess the performance of our AP selection algorithm based on *Network Fittingness Factor* and *Potential Game*. Our evaluation will focus on the following performance metrics:

- *Satisfaction*, which is the percentage of flows connected to the network with their served data bit rates higher than or equal to their given requirements, and updated for each new connection.
- *Throughput*, which is the average throughput reached at the end of the simulation by the *m* flows connected to the network.

We compare the performance of our algorithm against AP selection based on the Received Signal Strength Indicator (RSSI) as considered in the 802.11 standards [16].

Figure 4 shows the obtained results in terms of the satisfaction as a function of the number of active flows connecting to the network. From this figure, we can observe that AP selection solutions based on the *Potential Game* and on the *Network Fittingness Factor* outperform RSSI-based solution, with a satisfaction improvement reaching approximately 18% when the number of active flows *m*=2000.

Figure 5 shows the CDF distribution of the satisfaction of the *m* active flows when *m*=2000. The obtained results show that solutions based on the *Potential Game* and on the *Network Fittingness Factor* outperform the RSSI-based mechanism. For instance, the probability that the percentage of satisfied flows is less than the 100% is around 3% and 5% in the cases of *Potential Game* and *Network Fittingness Factor*, respectively, while in case of RSSI-based strategy this probability is approximately 21%.

Finally, Table 1 shows the results in terms of averaged throughput achieved by *m* active flows when *m*=2000 together with the average throughput required by the wireless users obtained using the CDF illustrated previously in Figure 2. From this table, we can observe that the best result is achieved when the AP selection algorithm based on the *Potential Game* is applied, which obtained the higher and the closest value to the requirements compared to the *Network Fittingness Factor*-based and RSSI-based solutions.

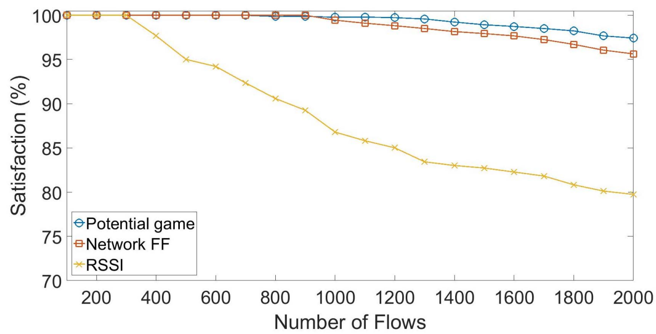

Figure 4. Average Satisfaction

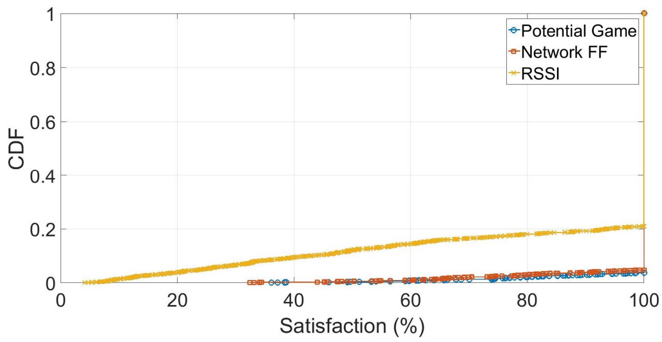

Figure 5. CDF of Satisfactions

Table 1 - Average Throughput

	Average Throughput (kbps)
Requirements	110.8
Potential Game	103.4
Network FF	96.1
RSSI	68

B. Discussion

These results prove that in a scenario such as the shopping mall use-case, our AP selection solutions yield better performance compared to the 802.11 standards. This is mainly due to the fact that these solutions allocate WLAN resources more efficiently while considering the QoS requirements of wireless applications. Moreover, both solutions do not incur high complexity, as it is linearly related to the number of flows connecting to the network.

We have already demonstrated the benefits of the *Network Fittingness Factor* in [2] and [3], which allows us to achieve significant improvements compared to common solutions found in the state of the art. While the results achieved in this paper show that the *Potential Game*, when applied to this use-case, outperforms the *Network Fittingness Factor* in terms of satisfaction and throughput by 3% and 7%, respectively, when the number of active flows m=2000. This improvement is due to a further optimised allocation of APs achieved by the *Potential Game* when the number of active flows is at its maximum.

However, this improvement comes at a higher complexity cost when compared to the *Network Fittingness Factor* as already explained in Section IV. Therefore, a trade-off could be made by the service provider between higher efficiency for the customers of the Kings Avenue mall and lower complexity when the SDN framework is used to manage large WLANs.

VI. CONCLUSIONS

This paper has presented the problem of AP selection in large scale WLANs through the study of a shopping mall use-case. We have investigated through simulations the impact of a smart AP association algorithm based on the Fittingness Factor (FF) metric, which considers the heterogeneity of the requirements for different stations accessing the network, on the performance of the WLAN studied in this use-case. The proposed AP selection algorithm is implemented in a framework based on SDN, which manages the APs distributed in the WLAN of the considered shopping mall use-case. We proposed two approaches in our smart AP selection that rely on the FF concept, and based on the so-called *Network Fittingness Factor* and a *Potential Game*, respectively.

In order to highlight the efficiency of the proposed solution, a comparison has been performed against the AP selection strategy suggested by the IEEE 802.11 standards. We have then demonstrated that our AP selection solutions yield better performance compared to the standards. Moreover, we have shown that the strategy based on the *Potential Game* outperforms the solution based on the *Network Fittingness Factor* at the cost of increased complexity. Therefore, this result gives to the service providers a trade-off between efficiency and complexity when the SDN framework is used to manage large WLANs.

As part of our future work we will consider an extended network model that will include also uplink applications. Moreover, the smart AP selection strategy presented in this paper will be also validated and assessed in the field trials included in the Wi-5 project [8].

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