Fast Spectral Assessment for Handover Decisions in 5G Networks

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***Abstract*—In this paper, we present a UE-driven light-weight mechanism for fast handover decision and efficient WLAN selection in the context of 5G networks. As the network deployments are expected to be denser and the mobile user will be offered a multitude of alternative short coverage range options to have her mobile traffic served, her roaming decision will be performance critical. While the current 3GPP standardization considers the use of network performance statistics of nearby WLANs for the UE-driven roaming selection to address the uncertainty of the shared wireless medium, their collection and processing inevitably affects the mobile user performance and inserts an accuracy-performance tradeoff. We introduce a spectrum assessment framework, that is based on commercial hardware and open-source software, to evaluate the conditions on the nearby WLANs and let the UE to infer their performance with minimum overhead relying on Duty Cycle evaluation and the RSSI metrics. Our ready-to-be deployed solution leverages the use of off-the-shelf equipment and commercial devices and enables fast decision procedures for the WLAN selection with low collection and processing overhead. We evaluate our mechanism by conducting testbed experiments. The results reveal performance gains in terms of UE's achieved throughput when enabling the proposed framework to infer the spectral WLAN conditions and decide for the AP to roam.**

***Index Terms*—5G-next generation networks, WLAN selection policy, fast handovers, spectral assessment.**

I. Introduction

A. Motivation

While mobile data offloading to wireless LANs seems to offer a promising solution against the so called capacity crunch problem[1] of cellular networks, its potential is currently limited by the uncertainty of the shared wireless medium and the low-performance WLAN selection mechanisms that are used to enable the intercommunication between 3GPP and non-3GPP RANs. Notwithstanding the existing standardized interworking solutions between 3GPP-enabled and WiFi access networks [2], [3], their usage have failed to exhibit the full interworking potential for networking efficiency, and merely achieved a relatively sufficient level of performance for delayed services [4]. As the cell and WLAN selection procedures are UE-initiated, each UE's decision for roaming is limited by the insufficient knowledge for the performance and conditions in

[1]According to Cisco VNI [1], the proliferation of smart devices and the corresponding unprecedented data demand, have resulted only for 2018 in a significant increase of 64% in global mobile data traffic as compared with 2017. Moreover, this demand is expected to be further raised from 11 to 49 Exabytes per month until 2021.

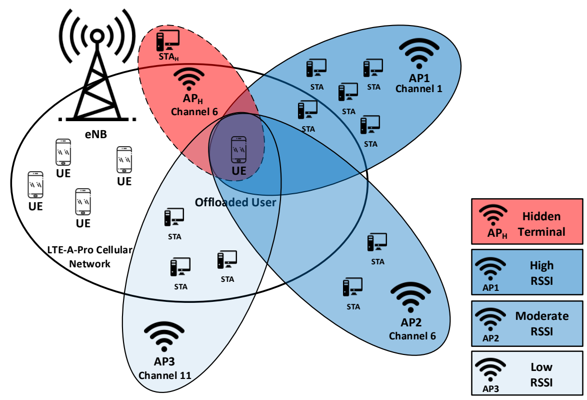

Fig. 1. An LTE-A macrocell serving mobile users that are partially in the range of different WLANs. The offloaded user decides the WLAN to roam. Relying her choice on the different RSSIs that she experiences is inadequate to infer the WLANs performance conditions and reach an accurate decision.

the nearby WLANs. However, a sophisticated mechanism that could provide frequent and accurate network state information from the nearby WLANs for even more accurate assessment, although meticulous, would heavily affect the throughput and latency performance due to the extra incurred burden for exchanging network state information messages.

Currently, the ANDSF (Access network discovery and selection function) and WLAN selection policy [3], [5] mechanisms provide a standardized functionality for network discovery and non-3GPP RAN selection and allows a UE obtain network/channel status information and AP parameters from the nearby eNBs or APs (e.g. RSSI, channel load), however, it does not specify how the UE should leverage this information to select the preferable point of service. So far the existing solutions implementing the ANDSF functionality cannot achieve the maximum performance gain, as this would require complex and cumbersome coordination and frequent and real-time communication of control signaling and information between the different nearby RANs. Moreover, the standard WLANSP (Wireles LAN Selection Policy) procedures are merely based on approaches for AP selection relying on the RSSI measurements ignoring well-known problems such as hidden terminal leading to undesirable RAN selection and poor performance.

Nevertheless, the fast and rapid selection of the most appropriate WiFi RAN for a UE to roam is one of the major challenges for (a) efficient resource management and fast speed communications (b) providing a smooth and seamless transition between different RAN technologies, in 5G next generation networks. As the small cell and dense network deployments of heterogeneous RAN technologies are expected to overlap in the rural areas, the mobile user will be able to simultaneous connect and dis-connect to different eNBs, or WiFi APs in order to communicate and receive service.

Furthermore, the tight integration of next generation cellular networks LTE-A-Pro with new radio interfaces to meet the 5G requirements for fast and low-latency communications renders solutions for simultaneous multi-connectivity and rapid handover highly attractive in order to enable faster mobility and common resource management.

B. Contribution

In this paper, we present a novel UE-driven decision mechanism for handovers and efficient WLAN selection in 5G networks. In Fig. 1 a representative use case scenario is shown. Different WLANs characterized by different RSSI levels are co-located in the vicinity of a 3GPP LTE cell and offer alternative point of services. Upon taking a roaming decision, the UE considers apart from RSSI also the perceived spectral conditions, in order to export optimal association decisions. To this end, the contributions of this work can be summarized as follows:

- *Assessment of the Wireless Spectrum Occupancy:* The proposed system enables a UE to elaborate and assess the perceived wireless spectrum conditions (Duty Cycle evaluation) from the nearby WiFi networks and take them also into its consideration for its WLAN association decision. Particularly, a UE[2] jointly considers the channel utilization that it detects and the received signal strength RSSI from the candidate AP.
- *Light-weight Mechanism:* In comparison to other works [6] for contention and traffic-load aware user association that require tight coordination and cumbersome exchange of channel state quality information between APs in the first-hop and second-hop neighbor, our mechanism requires minimum signaling overhead which tends to be the appropriate solution for fast handovers in the 5G domain.
- *A ready-to-be deployed Solution:* Finally, we propose a roaming decision framework for 5G communication systems that is based completely on conventional IEEE 802.11 hardware and leverages open source software. Our solution is ready-to-be deployed in commercial off-the-shelf devices, which strongly encourages its wide applicability in future communication networks without additional deployment costs.
- *Performance Evaluation:* We evaluate the above roaming decision framework using real hardware experimentation. We conducted extensive experiments in the NITOS testbed [7], and we showed that our decision framework can assist UEs for accurate WLAN selection when roaming with a minimum scanning overhead.

[2]We use also the term STA to refer to the UE that has been offloaded to the WiFi network.

The rest of this paper is organized as follows. In Section II, we present prior related work. Next in Section III, we present the proposed framework and describe in detail all its software and hardware components. Furthermore, in Section IV we conduct extensive experimentation in NITOS wireless testbed [7] to prove the validity of the proposed framework and to assess its performance in various network settings. Finally in Section V, concludes our work.

II. Related Work

Seamless interoperability with fast handover between cellular and WiFi networks pose significant challenges for alternative network discovery, persistent connectivity and traffic management. To this end, 3GPP defined the ANDSF, an entity within an evolved packet core (EPC) of the system architecture evolution (SAE) for 3GPP compliant wireless networks, that is leveraged to assist UEs to discover non-3GPP access networks (e.g. WiFi mesh networks) and assist in handover and offloading operation.

ANDSF offers the standard interface to operators in order to enable device-based policies for network discovery and access network selection policies to the UE. Unlike the static approach, that was adopted primarily in 3G networks, and utilized roaming lists, ANDSF is a dynamically adaptive solution for 4G & 5G network deployments of fast changing mobile environments in which rules and metrics evaluation determines which network to select based on particular objectives (usually defined by the operators and combined with pricing schemes [8]). The management of toggling between the access networks is both device dependent and network assisted using policies communicated to the user. In this way, ANDSF enables the operator to influence WiFi network usage and balance traffic to provide enhanced QoS. Moreover, the tighter integration of WiFi networks with the LTE-A-Pro as expected in the 5G era.

Intense research effort has been conducted in cellular systems for the alleviation of the capacity crunch problem, where the vast majority of the approaches steer the offloaded data to Wireless Local Area Networks (WLANs). There through, several works denote the significant energy and performance gains that could be obtained, when the offloading mechanisms are applied. More specifically, the authors in [4] present a solid experimental study for 3G networks, where the well known “on-the-spot” and “delayed” offloading schemes are evaluated in terms of efficiency and energy savings. Furthermore, other approaches [9] focus more on the trade-off between achieved performance and additional delay, in the offloaded links. Therefore, these works clearly denote how the Quality of Service (QoS) is considered in the offload case studies until now. Taking it a step further, the authors in [4], [10] declare how the delayed offloading schemes apart from energy savings, could also create financial benefits/profits for both mobile users and operators.

While mobile data offloading from cellular to WiFi networks appears to be an ideal solution for addressing the current cellular networks capacity crunch problem, on the other hand, significant performance drains are also observed lately in the commonly used IEEE 802.11 links which are leveraged to convey and serve the offloaded data. Both the tremendous wireless data demands and the lack of available spectrum, make the WLANs highly susceptible environments for efficient transmissions. This problem is further intensified as the ISM bands of 2.4 and 5GHz are also home for a large variety of protocols and RF devices. More specifically, in this limited spectrum portion multiple sources of light (IEEE 802.15.1 Bluetooth, IEEE 802.15.4 ZigBee) and heavy radio interference (caused by Microwave Ovens, Wireless Cameras), largely affect the performance of IEEE 802.11 links. As expected, the great variations on wireless channel conditions may arise the obvious question of how the performance QoS is guaranteed in these links.

An important amount of work have proven that both the intense coexistence of multi-protocol RF devices [11]–[13] and the rapidly interchangeable channel conditions greatly affect Wi-Fi performance. Additionally, strong emphasis has been given within the identification and selection of the proper networks for data offloading. More specifically, until now several approaches [14]–[17] investigate some of the practical and theoretical aspects associated with the WLAN's selection, condition and estimated capacity respectively.

Nevertheless, there is a noticeable lack of proposed works which take into account the performance fluctuations could arise from channel's external interference. In particular, Nguyen et al. [15] propose an offloading scheme with dynamic AP selection, based on both received signal strength (RSSI) and channel load metric exposed from APs in IEEE 802.11k networks. However, effects like hidden terminals which frequently occurred in dense Wi-Fi environments and largely affect the WLAN performance, are not considered in the aforementioned approaches so far.

III. Proposed Framework

Alongside with the increased expansion of wireless applications in recent years, the consequent lack of available spectrum became a hazardous threat for the communication performance in wireless networks. As a result, the unlicensed frequency bands (ISM) are currently over utilized, mainly due to the widely deployed IEEE 802.11 infrastructures in a small portion of wireless spectrum. Moreover, the unregulated transmissions from non-WiFi devices deteriorate the problem of the already reduced performance. Thereby, spectrum awareness in IEEE 802.11 systems gained a lot of research [13], [18] and industrial [19], [20] interest. Based on this mindset, we exclusively take advantage of PHY-layer spectral measurements that could be exported from commercial chipsets, in order to develop our proposed spectrum awareness decision framework.

A. Hardware

To assess and evaluate our framework's performance, we have leveraged NITOS wireless testbed [7] to conduct extensive experimentation. There, a large variety of wireless and wired resources are available to the experimenter remotely for evaluating experimental prototype implementations. As mentioned above, in this work we exclusively take advantage of Atheros commercial chipsets for facilitating the current spectrum analysis. Particularly, we employ the testbed's wireless nodes to act as the offloaded users and STAs in the available IEEE 802.11 networks. These nodes are equipped either with AR9380 or AR9880 PCI-e interfaces. Additionally, we use off-the-shelf TP-Link AC1750 dual band routers to act as APs. These routers include both AR9380 and AR9880-BR4A v2 wireless adapters, which are also directly compatible with the proposed spectral awareness mechanism. The spectral capabilities for all aforementioned wireless adapters are listed at Table I.

TABLE I
ATHEROS CHIPSET SENSING CAPABILITIES

Bandwidth / Sub-carriers (MHz) ($\mathcal{SC}$)	Chipset Type	
	AR9380	*AR9880 / AR9880-BR4A v2*
20/56	✓	✓
40/128	✓	✓
80/256	✗	✓

B. Enabling Spectrum Awareness

Undoubtedly, the primary objective for any spectrum aware framework could not be other than the fast and precise recognition of channel's conditions. Therefore, a proper way for quantifying the percentage of active transmissions should be adopted. Based on previously proposed approaches [13] we also use the widely adopted Duty Cycle (DC) metric and thus, we are able to discover in real time the presence of interference sources. More specifically, the proposed framework could be distinctly separated into the following phases:

Phase 1. *Collecting Spectral Measurements:* Initially, we have to trigger the wireless adapter for initializing the spectrum sense procedure. During this phase, the wireless interface collects raw spectral samples based on the user's requested parameters. As part of this work, we scan the spectrum under inspection using 20MHz non overlapping channels with central frequency $\mathcal{F}_c$ and using 56 FFT sub-carriers ($\mathcal{SC}$) resolution (The 1st Configuration Setting as shown in Table I). Thereafter, each spectrum instance obtained in 20MHz/56$\mathcal{SC}$ forms a spectral set ($\mathcal{S}$). Moreover, to achieve higher detection accuracy, we collect $|\mathcal{N}_s| = 250$ spectral sets for every channel scanned. ($\mathcal{N}_s$ denotes the set of samples that have been collected during the scanning process and correspond to a given central frequency $\mathcal{F}_c$). Bearing in mind that during this phase the wireless adapter will temporarily be out of conventional order, the aforementioned spectral parameters should be carefully adjusted. In such way, the framework's overhead will be reduced as much as possible and without losing valuable spectrum information. Extensive overhead experiments under various configurations are given in Section IV.

Phase 2. *Inferring Spectrum Utilization:* After the completion of the first phase, all the collected spectral measurements have already been reported to the device through the Linux proc filesystem. At this state and without any further processing, no useful information could be inferred about the percentage of the spectrum utilization. In order to do so, a user space algorithm has been developed, to convert the raw measurements to Duty Cycle utilization per frequency. The Duty Cycle is a metric that describes the percentage of time in which the power of the considered spectrum fragment exceeds a specific power threshold $\mathcal{P}_{\mathcal{TH}}$. We use $\mathcal{P}(\mathcal{S},\mathcal{F}_c)$ to denote the power of Spectral Sample $\mathcal{S}$ that has been collected on the central frequency $\mathcal{F}_c$. The rationale of our algorithm is described as follows: Initially, in a given $\mathcal{F}_c$ we calculate each spectral set's received power as shown in the following Eq. (1)

$$\mathcal{P}(\mathcal{S},\mathcal{F}_c) = \sum_{i}^{\mathcal{SC}} \mathcal{P}(i,\mathcal{S},\mathcal{F}_c), \tag{1}$$

where $\mathcal{P}(i,\mathcal{S},\mathcal{F}_c)$ denotes the power at each corresponding sub-carrier of spectral sample $\mathcal{S}$. Then we compare it with a predefined power threshold ($\mathcal{P}_{TH}$) [13]. If the calculated power is higher than the aforementioned $\mathcal{P}_{TH}$, we consider this spectral set "on". Thereafter, the precise percentage of Duty Cycle in this specific $\mathcal{F}_c$ could be inferred by applying Eq. (2).

$$\mathcal{DC}(\mathcal{F}_c) = \frac{1}{\mathcal{N}_\mathcal{S}} \sum_{S=1}^{\mathcal{N}_\mathcal{S}} on(\mathcal{P}(\mathcal{S},\mathcal{F}_c),\mathcal{P}_{\mathcal{T}H}), \tag{2}$$

where function *on* is defined as follows:

$$on(\mathcal{P}(\mathcal{S},\mathcal{F}_c),\mathcal{P}_{\mathcal{T}H}) = \begin{cases} 1 & \text{when } \mathcal{P}(\mathcal{S},\mathcal{F}_c) \geq \mathcal{P}_{\mathcal{TH}} \\ 0 & \text{otherwise.} \end{cases}$$

Thereupon, we repeat accordingly the appliance of Eq.(1) and Eq. (2) for all central frequencies $\mathcal{F}_c$ scanned. Thus inferring accurate results with regards to precise utilization of the frequency/frequencies. It is worth to be noted that the developed framework (Shell and C scripts) is applicable without additional software/hardware modifications and works under all IEEE 802.11 standard versions.

Phase 3. *Roaming Selection:* According to the 3GPP standard procedures, the roaming decision is initiated by the UE when it detects that the current communication conditions (within the cell or the AP where it has been associated with) are not sufficient to attain the desired communication performance for the data service that it has requested. For that reason, the UE periodically elaborates various types of measurements and statistical information, which could be provided by the WLAN selection policy or the ANDSF component[3]. According to [2], [5], WLANSP offers to the UE the following list of selection criteria: *CriteriaPriority, HomeNetworkIndication, PreferredRoamingPartnerList. MinBackhaulThreshold, MaximumBSSLoadValue, RequiredProtoPortTuple,PreferredSSIDList, SPExclusionList.* while the ANDSF may provide also access network discovery information, WLAN selection information, ePDG configuration information, inter-system mobility policy, the inter-system routing policies and the inter-APN routing policies.

1) Spectrum Aware WLAN Roaming Selection: The collected measurements regarding the WiFi APs statistics, in the case where the APs belong to a list of *trusted non-3GPP* networks could be passed to the EPC network and further processed by the ANDSF and WLANSP functionalities. Thus updating the criteria list and the corresponding parameters. In the case of *untrusted non-3GPP* networks, this info could be injected in the beacon packets. In this work, we assume that all the available AP candidates are listed as *trusted non-3GPP* networks. Moreover, there exist a set of $\mathcal{A}$ of $|A|$ access points and a set $\mathcal{U}$ of $|U|$ user equipment devices.

Our WLAN selection mechanism assesses the WLAN performance conditions by inferring jointly from the perceived spectrum occupancy and the RSSI measurements. By holding the trusted APs list and receiving the WiFi beacon frames, a UE can initialize the roaming procedure. Initially, each UE $u \in \mathcal{U}$ should be aware of its local spectral conditions, thus it performs Phases 1 and 2 only for the frequencies $\mathcal{F}_c$ which are used by the trusted available APs in its vicinity. We use $\mathcal{DC}_u(\mathcal{F}_c) \in \{0,1\}$ to denote the DC percentage that has been sensed and exported by the UE $u \in \mathcal{U}$ on a given frequency $\mathcal{F}_c$. Respectively, we periodically activate Phases 1 and 2 at the AP $a \in \mathcal{A}$ side and we export the corresponding DC value $\mathcal{DC}_a(\mathcal{F}_c) \in \{0,1\}$ only for its operating frequency $\mathcal{F}_c$[4]. Moreover, through the beacon frames the UE is able to retrieve the RSSI values $\mathcal{RSSI}_a$ for each listed available AP candidate. As a result, the predicted modulation and coding scheme ($\mathcal{MCS}_{ua}$) between UE $u \in \mathcal{U}$ and each candidate AP $a \in \mathcal{A}$ can be exported through Table II. Then, using the mapping table[5] that shows the corresponding theoretical rate which is mapped to a particular MCS, we can derive an estimation of the throughput. In this context, the least normalized capacity C_{ua} (Mbps) between a UE u and each available AP a can be calculated by applying Eq. (3).

$$C_{ua} = (1 - \mathcal{DC}_{\max}) * \mathcal{C}_{Th}, \tag{3}$$

where $\mathcal{DC}_{max} := \max\{\mathcal{DC}_u(\mathcal{F}_c), \mathcal{DC}_a(\mathcal{F}_c)\}$ represents the worst case scenario of the occupied spectrum, as this is perceived either in the UE or AP side. Therefore, $(1-\mathcal{DC}_{\max})$ represents the remaining spectrum. Additionally, $\mathcal{C}_{Th}$ is the theoretical data rate that could be achieved as this is derived from the predicted $\mathcal{MCS}_{ua}$. In this way, the UE u takes the roaming decision to an AP a, relying on the calculated normalized capacity values by selecting the AP $a^* \in \mathcal{A}$ that offers the maximum capacity potential. That is:

$$a^* = \max_{a \in \mathcal{A}} C_{ua} \tag{4}$$

IV. Evaluation

In this section, extensive experiments were conducted in order to highlight the proposed framework's superiority. All the scenarios were implemented and tested in NITOS wireless testbeds [7]. Specifically, the indoor isolated testbed was used for implementing the examined topologies. Although the

[3]The UE may retain and use this ANDSF and WLANSP information until new or updated information is received.

[4]The collected DC metric can be passed in the UE either using the WLANSP and ANDSF mechanism or a beacon frame.

[5]Table listed in http://mcsindex.com/ is derived from IEEE 802.11-2012 Standard - Sections 18.3.10.2 (802.11a OFDM), 19.5.2 (802.11g ERP), 20.3.21.1 (802.11n HT) and maps RSSI values to MCS indexes for the purpose of determining the data rates.

TABLE II
IEEE 802.11N SENSITIVITY THRESHOLDS

MCS (1-4 Spatial Streams)	***20MHz***	***40MHz***
	values in (dBm)	
0 / 8 / 16 / 24	-82	-79
1 / 9 / 17 / 25	-79	-76
2 / 10 / 18 / 26	-77	-74
3 / 11 / 19 / 27	-74	-71
4 / 12 / 20 / 28	-70	-67
5 / 13 / 21 / 29	-66	-63
6 / 14 / 22 / 30	-65	-62
7 / 15 / 23 / 31	-64	-61

proposed framework deals directly with external interference, the uncontrolled presence would produce inconclusive results.

A. Initial Experiments

Primarily, we deem essential to measure the total overhead added in the wireless chipset, every time the proposed framework is executed. The purpose of this experimental scenario is to highlight the performance drains (Mbps), compared with the detection accuracy of the proposed framework.

This particular experimental scenario contains two wireless transmissions, which will take place in the 2.4GHz ISM band. Initially, we use USRP B210 [21] in order to emulate a microwave oven's emission, which corresponds to 50% of channel's utilization. We use channel 5 (2432MHz) as the center frequency of microwave's emulated transmission and a bandwidth of 20MHz. Additionally, we set a high RSSI 20MHz wide IEEE 802.11n link, in which the proposed mechanism will be applied. We set the WiFi link intentionally at channel 11 (2462MHz) in order to be completely isolated from microwave oven's interference. Then, we initialize a WiFi transmission and more specifically, we send 100Mbps unidirectional UDP traffic from AP to STA.

The experimental results were produced by examining the following parameters: (a) the time spent t_{scan} on scanning a particular frequency $\mathcal{F}_c$ and (b) the interval time t_{int} which represents how often the AP/UE triggers the proposed framework and thus refreshes its spectral awareness. Initially, we set t_{scan} (10ms, 20ms and 50ms). In addition, for a different number of time intervals ranging from $t_{int} = 100ms$ to $t_{int} = 5000ms$, we have also run the same execution. In Fig. 2, we show the averaged experimental results, after conducting the aforementioned scenario 10 times for all parameter combinations. There, we can observe that the more frequent (low t_{int}) the proposed framework is executed, the higher performance drains occur. Additionally, the larger performance decays appear when the adapter scans the channel for $t_{scan} = 50ms$ comparing to $t_{scan} = 20ms$ or $t_{scan} = 10ms$. This is immediately explained as during the scan time the wireless adapter can not transmit or receive packets. Moreover, measurements with higher DC accuracy occur when the wireless adapter spends more scanning time on a frequency $\mathcal{F}_c$. More specifically, the exported DC values from the framework at 2432MHz (microwave's emulated transmission) were 44,82%, 48,43% and 49,97% when the adapter scans the $\mathcal{F}_c$ for t_{scan} =10, 20 and 50ms,

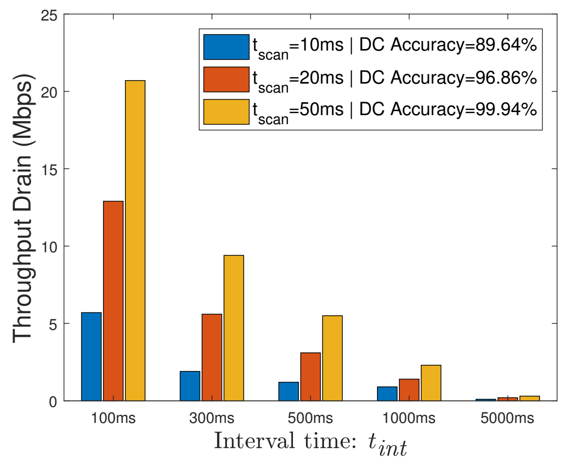

Fig. 2. Performance Drain Vs. Detection Accuracy at 2432MHz

accordingly. As noted above, the microwave transmission occupied half of the channel's capacity, and thus the expected DC percentage should be 50%. Furthermore, Fig. 2 shows that the DC accuracy is the same for a specific t_{scan} along different t_{int}, as the sensing procedure is not affected by the framework's execution time intervals.

B. Experimental Setup

At this point, a mobile user (UE) intends to leave the cellular network and has it's traffic demand served through the available WiFi AP candidates. We thoroughly examine how the throughput performance (Mbps) of a UE could vary depending on different AP association decision schemes. Specifically, the default RSSI-based, an approach which is only AP aware and our proposed decision mechanism are compared. The topology under examination is shown in Fig. 1.

In this experiment, three IEEE 802.11n 20MHz WLANs of different RSSI levels (high, moderate, low) are used, and act as the alternative point of service for a UE. The RSSI values that were received by the UE are -36dBm, -67dBm, -75dBm for AP1, AP2 and AP3, respectively. We configure these APs at channels 1, 6 and 11 accordingly to eliminate the potential interference among them. Additionally, there exist contending STAs, which are already associated with each AP. Particularly, AP1, AP2 and AP3 has five, three and two connected STAs, respectively. Each STA has a continuous bidirectional UDP traffic demand of 12Mbps from its AP. Finally, a fourth IEEE 802.11n 20MHz WLAN at channel 6 acts as a hidden terminal to AP2, thus none of its transmissions can be decoded and avoided by leveraging the CSMA/CA mechanism. During this experiment, we set a continuous moderate 30Mbps traffic demand at the hidden terminal link.

Table III summarizes the experimental results (average values of 10 executions) for a UE that applies our proposed WLAN selection framework. The first column is the DC percentage captured by the UE at channels 1, 6 and 11. Additionally, the second column states the DC percentage reported to UE from the available APs. It is worth to be noted that the large difference between $\mathcal{DC}_u(\mathcal{F}_c)$ and $\mathcal{DC}_a(\mathcal{F}_c)$ at the second row, indicates the potential presence of hidden terminal

TABLE III
EXPERIMENTAL RESULTS.

Scenario	$\mathcal{DC}_u(\mathcal{F}_c)$	$\mathcal{DC}_a(\mathcal{F}_c)$	$\mathcal{DC}_{\max}$	$\mathcal{MCS}_{ua}$	$\mathcal{C}_{Th}$	$C_{ua} = (1 - \mathcal{DC}_{\max}) * \mathcal{C}_{Th}$	C_{ua}^{REAL}
High RSSI (AP1)	87.1%	86.4%	87.1%	23	195 Mbps	25.155 Mbps	27.9 Mbps
Mod. RSSI (AP2)	89.7%	21.4%	89.7%	21	156 Mbps	16.06 Mbps	16.875 Mbps
Low RSSI (AP3)	46.1%	48.2%	48.2%	19	78 Mbps	40.4 Mbps	46.35 Mbps

at the UE - AP2 link. Since the values of $\mathcal{RSSI}_a$ are known to the UE through beacon frames, the proposed framework estimates the capacity (column capacity C_{ua} (Mbps)). Furthermore, we confirm that the $\mathcal{MCS}_{ua}$ values predicted are the same with these achieved during experimentaion, by using an external wireless monitor. Finally, the last column shows the actual throughput experienced by the UE when attaching to the respective AP. Comparing the last two columns indicates that the proposed framework achieves accurate throughput estimation for all the three available WLAN and infers the best candidate AP.

Regarding the part of the association decision: If the default IEEE 802.11 RSSI-based approach was selected, the UE would connect to AP1. In this case the UE would experience relatively low performance as AP1 would have the largest number of contending STAs associated on it and channel conditions would not been considered at all. Furthermore, if the association decision was based exclusively on AP's channel conditions, the AP2 would be chosen from UE. A typical example of such decisioning approach can be found in [15]. Even though this decision seems to be proper at AP's side, the UE's different spectral conditions dramatically affect the performance achieved. Finally, our proposed framework selects the AP3, although it offers the lowest RSSI and has more associated STAs than AP2. However, it turns out to be the best choice as it achieves the largest throughput performance compared with the two aforementioned approaches above.

V. CONCLUSIONS

In this work, we introduced a novel light-weight UE-driven mechanism for enabling fast roaming decision and WLAN policy selection in 5G networks. The proposed mechanism is built using commercial hardware and open source software, and offers a ready-to-be deployed solution for future wireless networks. It allows the UEs to thoroughly infer about the performance conditions in the nearby WLANs by incorporating also a fast spectral occupancy assessment on the available WiFi channels. Through extensive testbed experimentation, we demonstrated significant throughput performance gains for the offloaded UE when employing the proposed WLAN decision framework. The utilization of our framework comes with a minimum scanning and processing cost, which is totally compensated by the accurate inference of the wireless conditions, and hence the appropriate selection of the candidate AP/WLAN.

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