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Design, Integration and Slicing of non-3GPP DUs in 5G Networks: a Hybrid 5G-DU Approach

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***Abstract*—The countless needs of the modern world for connectivity have led to the rapid evolution of wireless networks and the creation of the latest and most current generations of 5G cellular networks and WiFi wireless networks that promise unprecedented levels of data speeds, low latency, and seamless connectivity. The integration of WiFi in the architecture of the 5th-generation cellular networks brings about an increase in the coverage, the exploitation of unlicensed spectrums, and the load-balancing of the network. Still, it also paves the way for creating a more robust and versatile next-generation wireless ecosystem. This paper presents and implements a 5G hybrid Distributed Unit (DU) architecture, integrating a WiFi DU into real-world 5G networks using the OpenAirInterface (OAI) RAN and 5GCN software. This work also tries to align the WiFi technology with the dynamic and flexible capabilities of 5G such as slicing. The WiFi functionality is extended, in order to support a User-Based Slicing scheme using Software-Defined Networking (SDN) combined with proper exploitation of the Type of Service (ToS) field of IP packets to prioritize traffic and manage network resources.**

***Index Terms*—5G, 5G-RAN, Heterogenous RAN, WiFi DU, Heterogenous RAN Slicing**

I. INTRODUCTION

One key enabler feature of the 5th Generation of Cellular networks over its predecessors is the functional split of the gNodeB (gNB) that paves the way for cloud-native deployments of the telecommunications Radio Access Network (Cloud-RAN). Prior generations were dominated mainly by non-split monolithic approaches, such as in the 4G - LTE era, the architecture consists of the Evolved Packet Core network (EPC) connected via the backhaul interface to the Baseband Unit (BBU), which handles a cellular network's digital processing and baseband functions. The BBU is connected via the fronthaul interface to the Remote Radio Unit (RRU), the entity that is responsible for transmitting and receiving wireless signals. The BBU and the RRU constitute the eNodeB (eNB) located at the cell site. This deployment, called D-RAN, suffers from inefficiency, leading to limited scalability, inflexible resource allocation, and high operational costs.

Due to these disadvantages, a new architecture was developed and proposed where the base station is split up, with the RRU remaining at the cell site and the BBU being placed far away from it at the hub site. This architecture, called C-RAN, is based on the logical separation of resources made possible by virtualization technologies, while the physical resources are shared in a flexible and dynamic manner. In the 5G era, network virtualization is done at the BBU side. The idea of breaking the BBU into smaller distributed entities -as virtualized services based on a cloud architecture- that would divide the computational processing among many nodes to optimize the networks was created because the traditional network architecture could not support the growing needs to maximize the capacity, the coverage and the traffic speed of the networks in an efficient way. The BBU can be divided into the Centralized Unit (CU) and the Distributed Unit (DU) within the 5G RAN. The CU entity hosts the network layer functionality; in contrast, the DU is more responsible for the Data Link Layer. Different functional splits, as proposed in 3GPP standards and researched in different studies, offer flexibility depending on radio network deployment scenarios, traffic constraints, and intended supported services. Significant research, including experimental evaluations of LTE networking stack splits at PDCP/RLC and MAC/PHY points, has been conducted. Based on [1] and [2], we used the PDCP/RLC split, or 3GPP Option 2, as the most effective based on these studies.

The functional split of the gNB into CU and DU brings flexibility and allows for scalable, cost-effective, and hybrid network deployments. Since splitting the stack at lower layers (e.g., the 3GPP Option 7.2 or 8 splits) requires high speed and low-latency access for the fronthaul [1], Option 2 split specifying the communication between the CU and DUs was pushed to standardization. The established F1 interface (also known as the midhaul) is being used for communication between the CU and the DU, and the F1 Application Protocol (F1AP) supports multiple DUs offering heterogeneous wireless network connections (e.g., 5G, LTE, and WiFi) in RAN perspective. While each DU is served from a separate CU (one-to-one relationship), a single CU should be able to serve several DUs (one-to-many relationship). This network design entails supporting multiple cells since each DU can support one or more cells, which makes it easier to develop networks based on micro-, pico-, and femto-cell architectures. Given the cost implications of 5G-DU deployment and operation compared to WiFi-based access, the integration of WiFi DUs emerges as a crucial strategy for cost-effective 5G networks.

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In this work, we explore the convergence of such technologies within the 5G network stack, allowing the operation of WiFi-based access from the base-station point of view for achieving network capacity augmentation. We investigate on how different technologies can be used concurrently for higher network capacity, and incorporate the idea of network slicing across this hybrid 5G Wireless Access Network. The main contributions of this work are the following:

- To increase 5G network capacity with non-3GPP technologies, integrated into the 5G networking stack as separate Distributed Units (DUs).
- To enable slicing information distribution and enforcement for non-3GPP technologies, complying with the 5G slicing model.
- To experimentally evaluate the contributions in a testbed environment, under real-world settings.

The rest of the paper is organized as follows: Section II provides an overview of the related literature. Section III provides our system model and Section IV evaluates our implementation. Finally, in Section V we conclude our work and discuss future directions.

II. RELATED WORK

In the pursuit of integrating non-3GPP Distributed Units (DUs) into 5G disaggregated Radio Access Network (RAN) architecture, it is crucial to consider the principles and frameworks outlined for untrusted non-3GPP accesses in 5G systems. Already from the first generations of cellular networks (e.g 3G), WLAN integration was considered crucial. The work [3] describes and proposes the integration of WLANs at the level of architecture and protocols as a separate part of 3G systems, which communicates through a proxy server with the PLMN in the 3G core network and not in the UTRAN access network. In the 4G era, as described in Release 12, two different approaches were introduced to converge WLAN into it: the LTE-WLAN Aggregation (LWA) and the LTE-WLAN Radio Level Integration with IPsec Tunnel (LWIP). The first method utilizes the Packet Data Converge Protocol (PDCP) as the aggregation layer [4], whereas the second one uses IPsec connections (IP-Layer 3 aggregation) [5].

In 3GPP release 15 of 5G [6], a new Network Function called Non-3GPP Inter-Working Function (N3IWF), playing the gateway role between the non-3GPP UE and the 5GCN, was introduced. N3WIF seems to be the descendant of LWIP methods of the 4G era and its conversion into a core network function of 5GCN. N3IWF directly interacts with the AMF, SMF, and UPF to manage mobility and access of non-3GPP UE, manage the PDU sessions, and establish data plane connections using GTPU tunnels, respectively. In [7], the authors perform an integration of WiFi and satellite technology, two non-3GPP wireless communication systems, into a 5G network utilizing the N3IWF to evaluate the performance of such integration in terms of timing of UE registration and PDU session establishment and also the RTT. The results show that the overhead introduced by the N3IWF, is negligible in real-world WiFi packets having a length of 1500 bytes. In [8] authors provide an overview and practical insights into the convergence, authentication, and authorization processes involved in integrating non-3GPP access networks (e.g. WiFi), into 5G networks using the N3IWF component.

One of the key enabler features of 5G is network slicing, which creates multiple virtual networks that multiplex the resources atop a cellular network to provide different services such as end-to-end connectivity and others. Performing slicing into RAN, called RAN Slicing, is one of the most challenging aspects of 5G since the dynamic wireless environment conditions prevail in the medium in addition to limited radio resources. Authors of [9] address the challenges of inter-slice interference by proposing an algorithm using heuristics to optimize RB (Resource Block) allocation to minimize inter-slice interference in multi-slice networks. New-era WiFi protocols such as IEEE 802.11ax and IEEE 802.11be integrate slicing methods such as Multi-SS [10], creating separated networks in a network management perspective, while focusing on handling multiple user demands and improving bandwidth utilization, not resource allocation contrary to 5G.

Integrating a WiFi access network into a 5G system implies the need to support similar features as that of slicing in our implementation. Targeting home networks, extensive research has been conducted regarding Network slicing in WiFi. The authors of the work [11] combine FlowVisor with OpenFlow networks to implement independent and isolated slices from each other to satisfy applications from different providers or with different network requirements. Apart from the available bandwidth of the channel, the slices share other essential network resources, such as the CPU of the network devices or even forwarding table entries. A different approach was followed in the paper [12], where the researchers see WiFi slicing as a resource allocation problem as a stochastic optimization challenge, using Optimization Theory to ensure minimum guaranteed bit rates and maximum queuing delays. The solution they propose is a packet routing algorithm that will manage the airtime of the medium corresponding to each slice, to achieve queue prioritization. One way to perform slicing into WiFi networks is to utilize a MAC-level slicing technique. Paper [13] presents a novel approach of MAC level slicing based on pausing and unpausing the MAC80211 software queues before the data is transferred to the NIC, enabling precise allocation of air-time to different virtual networks of a single physical Access Point (AP). This mechanism allows for real-time resource isolation in time based on a TDMA approach, where the medium access is divided into small slots, allowing fine-grained adjustment of the slice size during runtime. Nevertheless, none of the above works addresses how slicing can be applied when integrating non-3GPP technologies into the cell.

In this work, we progress beyond the current state of the art to develop, to the best of our knowledge, a prototype integrating WLAN as a non-3GPP DU to the 5G RAN. The work extends slicing capabilities to the non-3GPP network, by handling the scheduling at the PDCP level of the 5G stack and enforcing slicing decisions to the non-3GPP network.

III. SYSTEM MODEL AND ARCHITECTURE

This section describes the system architecture and our method to perform the slicing over WiFi DU. In our base architecture, we use as reference network stack the 5G stack, using the 3GPP Option 2 split described in [14] and demonstrated in [15], in which CU includes the protocols of the PDCP layer and above, and DU includes the RLC layer and below. CU, gNB DUs, and WiFi DUs are the primary entity components of this Heterogeneous RAN 5G Disaggregated architecture. In the following work, we analyze the implementation of the WiFi DU entity and how slicing is performed.

A. WiFi DU integration

For the WiFi DU, we utilized a handler developed for the 4G OAI architecture, to fulfill the communication protocol requirements of RLC and PDCP in the disaggregated RAN implementation, allowing us to follow the LWA aggregation architecture into integrating the WiFi DU on the 5G OAI architecture. This handler intervenes between the RLC and PDCP in the protocol layer stack, providing an interface for reliable communication in the control and data plane among these layers and enabling data transfer between multiple DU technologies and the CU. More details on the protocol of the agent are presented in our prior work [15], integrated into the LTE stack. The WiFi-DU registration process in the network does not follow the conventional process of 3GPP DUs. The CU is registering with the WiFi-DU, contrary to 3GPP DUs, which follow the opposite process and are responsible for their registration to the CU. The specific registration strategy was chosen because the support of WiFi DUs is given as a feature of the modified CU and for security concerns since it will be proactively configured to be assigned with corresponding WiFi DUs. Further investigation regarding the security aspects of our proposed system is within our future work. The WiFi stack considerably differs from the cellular network one concerning functionality. Different procedures must be followed, depending on whether data will be sent back to the CU via the F1 interface or to network UE via the WiFi NIC on the DU device. The WiFi DU also has the AP's role in the IEEE 802.11 wireless network system, and the UEs have to establish a connection with it. Regarding the UpLink (UL) dataflow of WiFi DUs, packets are received from UEs using the IEEE 802.11 protocol stack. So, the received payload (IP layer and above) should be encapsulated into the respective PDCP header for the PDCP instance running on the CU. In the DownLink (DL) dataflow, packets undergo the reverse process: unpack and strip the PDCP header and deliver the payload to the NIC driver on the DU device.

On the 5G-DU side, we use the same architecture as the 5G OAI, utilizing the F1AP protocol for control messages and the GTP-U protocol for the data traffic among the CU and the DU. Our strategy is to support one multihomed UE to be connected simultaneously to two DUs, one WiFi, and one 5G DU, in order to increase the overall network capacity. Each DU is responsible for managing and maintaining its own PDCP sequence number for the packets of each UE that it processes. Implementing a distributed individual PDCP instances architecture at each DU to our system leads to increased complexity to ensure consistency in handling PDCP sequence numbers due to the need for communication among the DUs, adding synchronization overhead to correct packet ordering and delivery for the higher layers. We chose to integrate a centralized PDCP instances architecture at the CU for unified management of sequence numbers of a UE, irrespective of the DU that processes them, by aggregating the sequence number of the PDCP entity from both DUs.

B. WiFi Slicing Mechanism

The stripped packet is an IP packet and its payload. In IP protocols, the ToS field provides a quality of service (QoS) mechanism used in networking routing functionalities to prioritize the network traffic, ensuring efficient utilization of network resources to deliver low-latency, high-throughput, or highly reliable service for the datagrams. We prioritize datagrams by changing the value of the Differentiated Services Code Point (DSCP)/Type of Service (ToS) field in the IP header. To effectively support the Quality of Service (QoS), a mac80211 driver has at least four priority queues, each of which is mapped to a different Access Category depending on its services (Table I). In descending order of priority, these Access Categories are as follows: Background (BK), Best Effort (BE), Video (VI), and Voice (VO).

TABLE I: Table Type Styles

User Priority	Access categories (ACs)	mac80211 queue (MQs)
1	Background (BK)	3
2		
0	Best Effort (BE)	2
3		
4	Video (VI)	1
5		
6	Voice (VO)	0
7		

As described in the IEEE 802.11 stack protocols, each of these four access categories is mapped to a User Priority (UP). UP is a value associated with a medium access control (MAC) service data unit (MSDU) specifying the quality of service class and the priority queue that each datagram belongs. The mapping between UPs, ACs, and MQs is shown in Table I.

The prioritization among different queues is achieved through different opportunistic channel access characteristics. More particularly, different MQs use different inter-frame periods to consider the medium idle before transmitting their datagram. Therefore, MQs with higher priorities will access the channel more frequently due to shorter inter-frame times between subsequent transmission attempts.

The ToS value of the IPv4 header determines the packet UP. The IPv4 ToS field maps into the UP as shown in Table II.

As we mentioned, the PDCP header is taken from the WiFi DU entity's DL stream, leaving only an IP packet and its payload. We accomplish WiFi-level slicing by assigning different ToS values to the IP packets, depending on the destination address, to control their forwarding to UP queues.

TABLE II: ToS-UP mapping

ToS val	User Priority
0-31	0
32-63	1
64-95	2
96-127	3
128-159	4
160-191	5
192-223	6
224-255	7

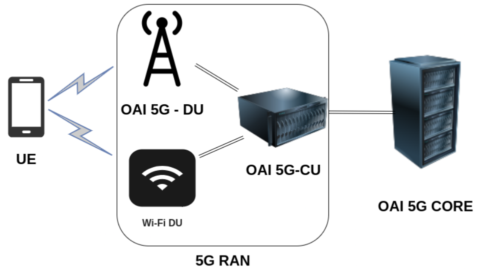


Fig. 1: 5G Disaggregated Architecture

Unlike the traditional WiFi protocols, that distribute equal channel capacity among the connected stations, our proposed system implements a User-Based Slicing approach. The framework prioritizes the clients based on the Type of Service (ToS) value that their packets will be assigned. In this system, clients allocated to a high-priority queue will access the channel more frequently, disrupting the fair distribution of channel resources leading to their prioritization. This approach mitigates the potential starvation of low-priority clients by leveraging the driver mechanisms designed to address this imbalance.

IV. EVALUATION

Extensive experiments were performed in this part to demonstrate the viability of the proposed idea. To evaluate our implementation, we used the NITOS testbed, part of the SLICES-RI [16], an open accessible infrastructure, one of the most extensive experimental facilities in Europe, located in the University of Thessaly, that offers highly programmable, remotely accessible technologies to users worldwide.

A. Experiment Setup

We deployed a Heterogeneous RAN 5G Disaggregated network in the NITOS testbed, an RF-isolated environment, based on a simple architecture in which four nodes are used to deploy the 5G Core network, the CU, the 5G-DU and WiFi-DU in order to evaluate our proposed network architecture. For the 5G-DU, two different USRPs, B210 and N310 were utilized to perform experiments and to compare their performance in real environments. For the UEs, two additional nodes equipped with the 5G dongle Quectel RM510Q-GL and an Atheros AR9380 WiFi NIC card were used. The WiFi-DU node is also equipped with the Atheros AR9380 WiFi NIC card to support the IEEE 802.11ac [17] protocol suite. The described architecture is shown in Figure 1.

The 5G Core Network's functionality is provided from the OAI 5G core, where we chose the basic deployment of NRF, TRF, UDR, UDM, AUSF, SMF, AMF, and UPF network functions. For the 5G RAN, we utilized the OAI-RAN. Regarding the 5G-DU, we did not make any changes to the source code provided by OAI. In contrast, for the 5G-CU, we integrated the library and a PDCP aggregation mechanism to support a UE connected to multiple DUs, as described in section III, and we implemented two basic selection interface policies based on Round Robin and Flooding schemes.For the WiFi-DU, we followed the same strategy as in [15]. We created a Python-based agent using the Google protocol buffers library to create a messaging exchange scheme among the handler integrated into the 5G-CU and the WiFi-DU. This agent receives the CU messages, retrieves the payload, and injects it into the AP WiFi device using a lookup table to link each UE RNTI to a WiFi NIC MAC address. The RNTI information of each UE is propagated to each WiFi DU upon registration of a new client with the 5G network, by the CU.

As proposed in the previous section, we achieve user-based slicing at the WiFi level by assigning different values to the IP packet's ToS field depending on its destination UE, according to preamble decisions. To achieve the shortest possible delay when configuring the IP packet for its prioritization, we decided not to configure this modification through appropriate libraries at the application level, but rather to pass the packets to an Open vSwitch (OvS) instance that uses programmable flows to support the appropriate modifications (ToS changes). As shown in Figure 2, to support two user-based slices with different priorities we connected two virtual ethernet interfaces and the WiFI NIC to an OVS. In our proposed solution, we establish a corresponding number of veths to the available ACs, to enable the assignment of each client to a distinct link that corresponds to a specific AC. Since virtual Ethernet devices are always made in pairs, two more virtual interfaces and the links required to complete the connection between these pairs were configured. One interface from the pair connects to OvS, and the other is forwarding packets to OvS from our agent. In the agent's DL dataflow, we modified the application according to the following functionality: depending on the priority we want to assign to each packet, the packet traffic is split across the two veth interfaces. OvS is programmed to change the ToS value on packets arriving at one of the two veth interfaces and forwarding them to the WiFi interface. We change the routing based on the destination address, or the client, between the priority and non-priority links every predetermined number of packets, to achieve the channel distribution in percentages.

The AP functionality of the WiFi DU was set up using the nl80211 and the ath10k_pci driver. The chosen operation wireless channel was 36, with the hardware mode set to operate in the 5 GHz band. The 802.11ac standard was enabled to leverage the benefits of High Throughput (HT) and Very High Throughput (VHT) capabilities. The VHT capabilities were fine-tuned with features such as LDPC coding having a channel width of 80 MHz and a center frequency of 5210 MHz. WiFi Multimedia (WMM) was activated for enhanced Quality of Service (QoS), playing a crucial role in our slicing mechanism. This configuration maximizes the transmission speed in the WiFi medium for our experiments.

For the 5G DU setup, we tested two USRPs, the b210 and n310, to measure their performance in real environments. We

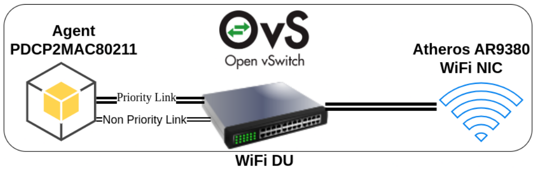
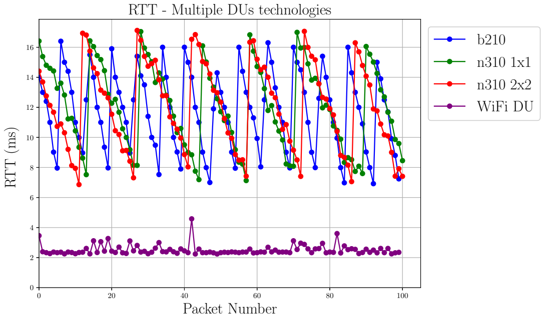


Fig. 2: WiFi DU slicing architecture

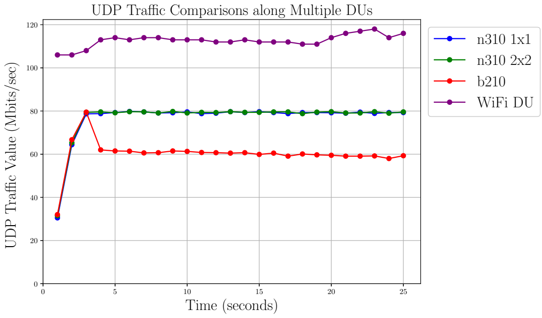
completed tests using USRPs B210 and N310, using 1x1 and 2x2 transmission schemes, to determine the best configuration that minimizes the round-trip time (RTT), increases throughput, and offers stability to the connections, the results of which will be presented in IV-B. Both USRPs operated in N78.

B. Experiments

In this subsection, we present the results of our experimental evaluation. Firstly, we compared the 5G-DU and the WiFi DU in terms of the RTT and the throughput speed among these technologies. This comparison offers insightful information about the advantages and limitations of each technology in our testbed setting. Following this, we illustrate the results of the proposed WiFi-DU slicing scheme, in an effort to integrate RAN slicing into the WiFi-DU implementation.



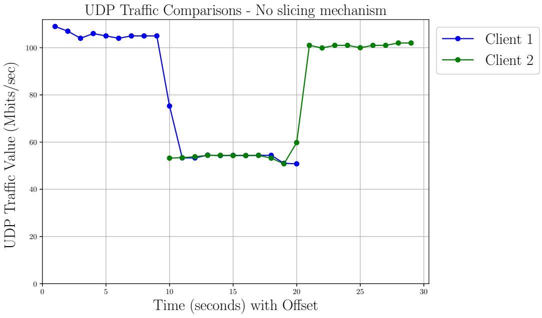
(a) RTT of packets across multiple DUs technologies



(b) DL UDP traffic across multiple DUs technologies

Fig. 3: RTT and DL UDP traffic across heterogeneous DUs

Many applications that 5G aims to support are latency-sensitive applications, such as virtual reality (VR), augmented reality (AR), autonomous driving, and industrial automation, highlighting as one of the most fundamental metrics to evaluate the importance of a WiFi DU integration into 5G architecture the RTT. To test our implementation, we utilized the ping command to generate one hundred ICMP packets from UE to the N6 interface of the UPF, which is responsible for the communication between the 5G network and the PDN, to obtain precise experimental results. As seen in Figure 3a, the integration of WiFi DU supports the usage of WiFi DU for transmitting UE packets resulting in a very short RTT time for the packets compared to that of the 5G DU, regardless of the USRP and stream scheme used. The mean values of RTT for the WiFi DU, 5G-DU b210, 5G-DU n310 1x1, and 5G-DU n310 2x2 are 2.509, 11.752, 12.01, 12.04 ms, respectively. The results denote that the WiFi DU outperforms the tested 5G DUs for the RTT metric.



(a) UDP transmission to two stations without slicing

(b) UDP transmission to two stations slicing supported

Fig. 4: DL UDP traffic for slicing, and non-slicing

To continue evaluating the proposed system, we used another key metric of the 5G, the application DL throughput. The DL throughput evaluation is done by generating UDP traffic from the N6 interface to the UE via iperf. Figure 3b illustrates that the DL throughput via the WiFi DU outperforms the 5G DUs since we managed to succeed at over 100 Mbps data transmission speed, where 5G-DU b210 managed to succeed at a speed of around 50 Mbps, and 5G-DU n310 1x1, and 5G-DU n310 2x2 around 60 Mbps. This performance in DL throughput highlights the significant contribution to the increased network capacity of this hybrid 5G system.

As far as the uplink transmission is concerned, the achieved transmission speeds differ to a large extent. 5G DU supports an average transmission speed of 3.95 Mbps, while with WiFi DU, 155 Mbps, achieving 39.24 times faster connectivity.

One of the challenges of integrating WiFi technology into the 5G architecture was the design of a slicing scheme as well as the co-existence of multiple clients. WiFi tends to distribute equally the available bandwidth among all active clients. This behavior is illustrated in Figure 4a, where we conducted an experiment in which the same amount of UDP traffic was generated from the N6 interface to two UEs via iperf. In the initial phase of the experiment, the first 10 seconds, we exclusively generate traffic to station 1, allowing it to monopolize the channel and to succeed DL traffic speed of over 100 Mbps. In the second phase of the experiment, after 10 seconds, we also began to generate traffic to station 2, which leads to equal distribution of the medium since both stations tend to succeed a throughput of 50Mbps. When the transmission to station 1 ends after 10 seconds, station 2 monopolizes the channel (100 Mbps).

To evaluate our proposed WiFi slicing mechanism, we replicated the previous experiment with a key modification of assigning UEs to different user-based slices as described in section III-B and illustrated in Figure 2. Station 1 is proactively prioritized and assigned to the priority slice with VO AC, the AC with the highest priority, and assigned a ToS value of 0xb8. Station 2 is assigned to a non priority slice having a ToS value of 0x04, belonging to the BK access category, which has the lowest priority. As shown in Figure 4b, in the first phase of the experiment Station 1 monopolizes the channel, achieving DL throughput of 100 Mbps. The channel's resources are unequally divided when station 2 started to receive traffic since the clients are now assigned to different ACs with different opportunistic channel access characteristics, giving different channel access priorities. Instead, station 1 continued to operate at a higher throughput of 75 Mbps, while station 2 only managed 37 Mbps. This means that station 1 used about 70% of the channel capacity, which is a significant increase from the 50% seen in the non-sliced experiment. Prioritization continued until the end of station 1's transmission, at which point station 2 monopolized the channel getting over 100Mbps.

Based on our results, we can see that integrating WiFi DU into a 5G network offers a significant reduction in the RTT time for UEs, as long as improvements over the transmission data speed result in increased network capacity. WiFi vulnerabilities regarding the co-existence of multiple clients are solved by our slicing mechanism in which we can share the medium according to their demands.

V. CONCLUSIONS

In this study, we have implemented a hybrid distributed unit 5G network architecture by integrating a WiFi DU into real-world 5G networks using the Open Air Interface (OAI) RAN. Our proposed system architecture leverages Software-Defined Networking (SDN) and the Type of Service (ToS) field of IP packets to implement frequency slicing among clients. We conducted experiments in a low-interference real-world environment in order to demonstrate the viability of our proposed architecture. The results indicate that the WiFi integration offers the minimum packet latency and the maximum data throughput among the tested 5G DUs deployments, and thus can be potentially used for augmenting the network capacity and providing low latency services over the non-3GPP DU. In the future, we plan to expose our system to real-world environments, under non-stable and fluctuating WiFi conditions, such as interference and congestion to illustrate the behavior of our proposed implementation. We additionally want to investigate our security vulnerabilities as well as deploy schemes to address the security and reliability aspects of the system. We foresee extending our scheme towards a more fine-grained control of the slicing mechanism for the non-3GPP DU, as well as exposing a programmable interface for handling the network with an O-RAN based approach.

REFERENCES

[1] L. M. P. Larsen, A. Checko, and H. L. Christiansen, "A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 146–172, 2019.

[2] N. Makris, P. Basaras, T. Korakis, N. Nikaein, and L. Tassiulas, "Experimental evaluation of functional splits for 5G cloud-RANs," in *2017 IEEE International Conference on Communications (ICC)*, 2017.

[3] A. Salkintzis, "Interworking techniques and architectures for WLAN/3G integration toward 4G mobile data networks," *IEEE Wireless Communications*, vol. 11, no. 3, pp. 50–61, 2004.

[4] Intel and Qualcomm, "New WI proposal: LTE-WLAN Radio Level Integration and Interworking Enhancements," 2015.

[5] Alcatel-Lucent, "Revised WID: LTE-WLAN Radio Level Integration and Interworking Enhancements," 2015.

[6] 3GPP, "3GPP TR 23.501 v15.3.0 (2018-09), 3rd Generation Partnership Project; Technical Specification; 5G; System Architecture for the 5G System ," 2018.

[7] M. Luglio, M. Quadrini, C. Roseti, D. Verde, and F. Zampognaro, "Performance evaluation of untrusted non-3GPP Access to a 5G Core Network via satellite," in *2022 International Symposium on Networks, Computers and Communications (ISNCC)*, 2022.

[8] M. T. Lemes, C. B. Both, A. C. D. O. Júnior, and K. V. Cardoso, "A Tutorial on Trusted and Untrusted non-3GPP Accesses in 5G Systems - First Steps Towards a Unified Communications Infrastructure," *CoRR*, vol. abs/2109.08976, 2021. [Online]. Available: https://arxiv.org/abs/2109.08976

[9] C. Yang, T. Wang, Z. Xiao, and S. Wang, "A Suggest-And-Improve RAN Slicing Strategy for Mobile Networks," in *2022 International Conference on Wireless Communications and Signal Processing (WCSP)*, 2022.

[10] M. Nerini and D. Palma, "5g network slicing for wi-fi networks," in *2021 IFIP/IEEE International Symposium on Integrated Network Management (IM)*, 2021.

[11] Y. Yiakoumis, K.-K. Yap, S. Katti, G. Parulkar, and N. McKeown, "Slicing Home Networks," in *Proceedings of the 2nd ACM SIGCOMM Workshop on Home Networks*, ser. HomeNets '11. New York, NY, USA: Association for Computing Machinery, 2011. [Online]. Available: https://doi.org/10.1145/2018567.2018569

[12] M. Richart, J. Baliosian, J. Serrat, J.-L. Gorricho, and R. Agüero, "Slicing With Guaranteed Quality of Service in WiFi Networks," *IEEE Transactions on Network and Service Management*, vol. 17, no. 3, pp. 1822–1837, 2020.

[13] S. Zehl, A. Zubow, and A. Wolisz, "Hotspot slicer: Slicing virtualized home Wi-Fi networks for air-time guarantee and traffic isolation," in *2017 IEEE 18th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, 2017.

[14] 3GPP, "3GPP TR 38.801 v14.0 (2017-03), 3rd Generation Partnership Project; Technical Report; Technical Specifications for Cloud Radio Access Network," 2017.

[15] N. Makris, C. Zarafetas, P. Basaras, T. Korakis, N. Nikaein, and L. Tassiulas, "Cloud-Based Convergence of Heterogeneous RANs in 5G Disaggregated Architectures," in *2018 IEEE International Conference on Communications (ICC)*, 2018.

[16] S. Fdida, N. Makris, T. Korakis, R. Bruno, A. Passarella, P. Andreou, B. Belter, C. Crettaz, W. Dabbous, Y. Demchenko, and R. Knopp, "SLICES, a scientific instrument for the networking community," *Computer Communications*, vol. 193, pp. 189–203, 2022.

[17] R. De Vegt, "802.11ac usage models document," *IEEE 802.11-09/0161r2*, Mar 2009. [Online]. Available: https://mentor.ieee.org/802.11/dcn/09/11-09-0161-02-00ac-802-11ac-usage-modeldocument.ppt