A Comparative Measurement Study of Commercial WLAN and 5G LAN Systems

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***Abstract*—In this study, we present the first measurement study of commercial IEEE 802.11 Wi-Fi wireless local-area network (WLAN) and 3GPP 5G LAN (*i.e.,* CBRS) networks in terms of latency, packet drop, and throughput. As the number of downlink and uplink traffic increases in the WLAN network, we observed significant number of packet drops and increased latency on the delay sensitive traffic, especially in mobility test cases where mobile devices roam from one Access Point (AP) to another AP. On the other hand, in both static and mobility test cases, packet drop rate of 5G LAN is consistently low at the desired target level due to interference free spectrum channel and efficient allocation of radio resources at MAC scheduling. Also, in the 5G LAN network, the Celona Micro-slicing feature guarantees minimum latency in a consistent manner across different test conditions. During the capacity experiments, we observed that, as the load increases, 5G LAN is able to guarantee fair allocation of radio resource among the connected users compared to WLAN system. In the end, we ran test with realistic enterprise use-case applications such as Zoom, Bar-code scanning, VOIP, and Camera to observe and analyze the user experience in WLAN and 5G LAN systems.**

Keywords: Shared Spectrum, CBRS, Unlicensed, Wi-Fi.

I. Introduction

In order to satisfy the demand of new emerging applications like AR and VR, cellular mobile network operators (MNO) and multiple-system operator (MSO) deployed more small cells in indoor and outdoor environment. IEEE 802.11 Wi-Fi technology (WLAN) is deployed in enterprises is a great indoor technology to satisfy the demand of mobile users for high data rate applications. On the other hand, cellular operators deploy more small cells in 4G and 5G technologies mostly outdoor since the distributed antenna system (DAS) based solution leads to high deployment cost when it comes to local and indoor deployments for enterprises. Furthermore, these traditional cellular deployments usually do not integrate with enterprise local area networks (LAN). Recently, the machine critical applications such as Machine to Machine (M2M) [1] and IoT (such as autonomous guided vehicles (AGVs), cameras) play a key enabler in the enterprise deployments, for example, warehouse, campus, office environments, smart city and ports, etc. However, the existing technologies such as traditional cellular and Wi-Fi typically fall short of meeting the strict requirements of mission critical applications for mobile devices in these enterprises since the enterprise deployment requirements in terms of latency, jitter and packet error rate criteria are completely different from consumer applications.

The recent release on locally available clean spectrum, *i.e.,* Citizenship Broadband Radio System (CBRS [2]), gains more attraction for the private deployments in the enterprises scenario. The primary user in this band is military and radar communication and its free to access when there is no incumbent nearby. The whole available bandwidth in this technology is 150 MHz which consists of 15 channels with 10 MHz per channel. For the initial BS operation, the radio needs to communicate their requirements in terms of transmission power, indoor or outdoor, bandwidth, channel and operating frequency with the centralized controller known as Spectrum Assisted System (SAS). After the successful spectrum grant response, the BS will be ready to operate on the dedicated channel and frequency.

In this paper, we compared the commercial Wi-Fi and cellular 5G LAN network (the **first real enterprise-level deployment** operating on CBRS) in terms of latency, packet drop and throughput. We observed that, as the load (traffic) and the number of users increases in the system, the Wi-Fi is challenged to guarantee the performance compared to the 5G LAN[1]. In the end, we ran test with realistic use-case applications such as Zoom, Bar-code scanning, VoIP, and Camera to observe and analyze the user experience in WLAN and 5G LAN (*i.e.,* CBRS) systems.

II. Background

A. WLAN 5GHz Channelization and Access Mechanism

In today's world, the Wi-Fi APs are deployed and operates on both 2.4 and 5 GHz, but typically there are less number available spectrum and more interference in 2.4 GHz. Due to higher availability of spectrum, the WLAN tests in this study where run in 5 GHz channel. The channelization used by WLAN in 5 GHz, spanning 5.15 GHz to 5.85 GHz [4]. These are designated U-NII bands (Unlicensed National Information Infrastructure) divided into three categories with different usage rules. U-NII-1 and U-NII-3 bands do not have any restrictions on usage other than transmit power limitations. However, since radar systems are also deployed in the U-NII-2 bands as primary users, unlicensed devices that wish to use U-NII-2 are required to implement Dynamic Frequency Selection (DFS) [4], whereby the incumbent radar signal must be

[1]The radio network can be LTE or NR in the enterprise or warehouse deployment. The spectrum used on both technologies is CBRS. For the rest of the document, LTE is referred as 5G LAN [3].

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sensed and if detected at a certain level the unlicensed device must vacate that frequency band in accordance with a timing protocol. Since these procedures add additional complexity to devices, the U-NII-2 band is sparsely used by the WLAN. Therefore, even though there is a total of about 560 MHz available, only the U-NII-1 and U-NII-3 bands, a total of 160 MHz, are heavily used. Conversely, WLAN uses 20 MHz, 40 MHz, and 80 MHz wide channels.

As specified by IEEE 802.11 standard, the WLAN adopts the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), which means that a station can only transmit if the channel is sensed to be idle and the station has not just completed a successful transmission [5]. Otherwise, if the channel is busy during the DCF Interframe Space (DIFS) sensing period or the station is contending after successful transmission, the station persists in monitoring the channel until the channel is sensed idle for a DIFS period. The WLAN system also supports different traffic categories like background, best effort, video, and voice, with different transmission opportunity based on contention window min and max. Suppose there are n stations that contends on one channel and transmits with probability τ, then we have

$$P_{tr} = 1 - (1 - \tau)^n. \tag{1}$$

As n increases, *i.e.,* the network is more crowded. It is more likely that more than one station transmits in each times slot, and the successful transmission probability

$$P_s = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \tag{2}$$

decreases. Hence, it is expected that the throughput decreases and the collision probability increases when the network is more crowded. The theoretical analysis also supports the simulation of average throughput versus the number of APs shown in Table IV.

B. LTE and 5G NR Mechanism

In LTE and 5G NR the radio resources are allocated in a centralized scheduling manner, a Resource Block (RB) is the smallest unit of radio resource allocated to a mobile user equipment (UE). For example in LTE, RB equal to 180 kHz bandwidth over a transmission time interval (TTI) like one subframe. Each RB contains 12 sub-carriers, each with 14 OFDM symbols, equaling 168 resource elements (REs), with the sub-carrier spacing (SCS) of 15 KHz and 30 KHz for NR. If the eNB acquires the channel before the start of the (next) LTE and NR slot, it may need to transmit a reservation signal to reserve the channel. After the transmission period, the receiver (or receivers) sends ACK if the symbols are successfully decoded. The approach to allocating radio resources is completely different from the WLAN CSMA network. In WLAN, all the clients need to contend for the medium for the Up-link (UL) and Down-Link (DL) transmission but in LTE and NR all the UEs got allocated radio resources based on the scheduling algorithm in the MAC layer, so there is no contention or inefficient spectrum usage and all resources can be fully utilized to cover UEs due to centralized scheduling approaches of LTE and NR.

C. CBRS Spectrum Operation Model

The CBRS private network utilizes the LTE/NR technology and operates on the 3GPP band 48 of radio frequency spectra from 3.5 GHz to 3.7 GHz (*i.e.,* 150 MHz) for 3 types of users namely: (a) Tier 1: Incumbent Users (e.g. the Navy radar and satellite system) (b) Tier 2: Priority Access License, PAL (e.g., private organizations such as hospitals, universities, factories) (c) Tier 3: General Authorized Access, GAA (e.g., unlicensed users such as phones, tablets, laptops, home routers). Originally, this band was reserved for the US Department of Defense, namely US Navy radar systems. However, the Federal Communications Commission (FCC) dubbed the 3.5 GHz band the "innovation band" to be opened to new mobile users in 2015. The 1st tier incumbent is protected against interference from PAL and GAA users. PALs are awarded to the highest bidders and allow coverage on a county-by-county basis. A single PAL covers a 10 MHz channel within the 3550-3650 MHz band and is assigned in 10-year renewable blocks. PALs must accept interference from Incumbent Access users but are protected from interference from the GAAs, *i.e.,* unlicensed users who are last in line to use the spectrum across the 3550-3700 MHz band. Since this tier is of the lowest priority, interference from any other tier or other GAA users is allowed to happen.

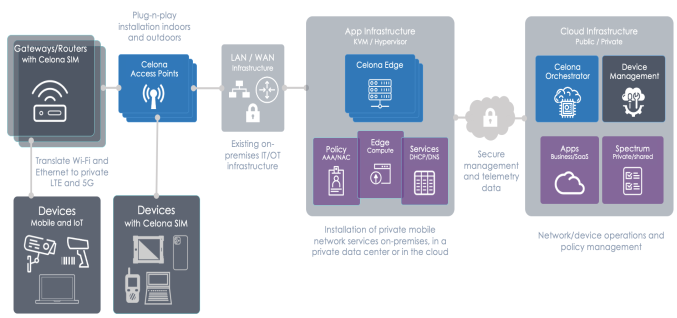

Fig. 1: 5G LAN End to End Architecture.

III. 5G LAN and Wi-Fi End to End Architecture

In this section, we discuss the end-to-end connection architecture procedures for 5G LAN and WLAN system.

A. 5G LAN End to End Architecture

Celona's 5G LAN architecture solution provides all requisite components for the private mobile network to function well on the air-medium: Celona Radio Access Network (RAN) connect to the indoor and outdoor LTE/5G APs, edge compute services on-site including the Evolved Packet Core (EPC) or 5GC functions as defined in the 3GPP standards, cloud orchestration for network operations and subscriber or SIM management, and integration with the Spectrum Access System (SAS) regulatory systems certified by FCC for the use

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TABLE I: WLAN Experiment Parameters

Parameter	Value
Number of WLAN APs	3
WLAN AP Channels	44+ 48, 108 + 112, 124 + 128
WLAN Frequency and Band	5 GHz: 20 MHz, 40 MHz, and 80 MHz
WLAN AP Transmission Power	15 dBm, 15 dBm, and 17 dBm
Channel Selection	Centralized S/W Controller
Number of WLAN Clients	5
WMM	Enabled
WLAN Client Devices	Google Pixel (4)
Tools	Ipref and Ping
Monitoring S/W	Wireshark

TABLE II: Celona Experiment Parameters

Parameter	Value
Number of Celona APs	2
Number of Bandwidth per AP	40 MHz (20 + 20)
Operating Band	48
Operating Frequency	3570, 3630, 3650, 3690
Channel Selection	SAS
Micro Slicing	Enabled
MIMO	2 x 2
Carrier Aggregation	Enabled
Tools	Ipref and Ping

of the private CBRS spectrum. Fig. 1 shows the end-to-end architecture for 5G LAN.

Celona's Self-Organizing Network (SON) or Real time Intelligent Controller (RIC) functions will adapt to shared spectrum assignments to ensure that the use of the frequency channels in the specific geo-location of the radios are coordinated per regulatory specifications. For enterprise IT departments, there is no need to separately acquire licenses to integrate with government certified spectrum sharing systems – as this is handled automatically by Celona software. Within an enterprise cellular network, it is up to the Celona network to coordinate and automatically make the necessary frequency assignments to its AP radios.

B. 5G LAN Micro Slicing

Micro Slicing is a powerful technology that allows precise control over resource and service allocation for different groups of applications and devices. Network administrators can use Celona Orchestrator or its developer APIs to customize the network settings by a device or application specific basis. It offers control and adjustments to numerous service types, including data throughput, quality, latency, reliability, and network access policies among others. Fig. 2 shows the Celona's 5G LAN micro slicing feature.

This enables users to set aside guaranteed portions of the network dedicated to the smooth functioning of the respective device and application groups. Every Celona Micro Slicing policy proposed can be supervised by the enterprise within the Celona Orchestrator, which allows for adjustments to be made instantly when necessary. The platform also records application-specific service level agreements (SLA) and key performance indicators (KPI) across all devices, granting complete user visibility of device performance across the spectrum.

Celona Micro Slicing has been proposed to accelerate private LTE/5G wireless deployments within the enterprise - and as a result, it allows enterprises to control costs for end users while maintaining higher flexibility and efficiency. Because this technology grants control over network resources, end users are able to avoid deploying unnecessary resources to devices that only utilize a fraction of their potential.

C. WLAN End to End Architecture

Since Wi-Fi operates on unlicensed spectrum, anyone can launch their own wireless network wherever they please. Wi-Fi's simplicity makes it one of the most popular wireless

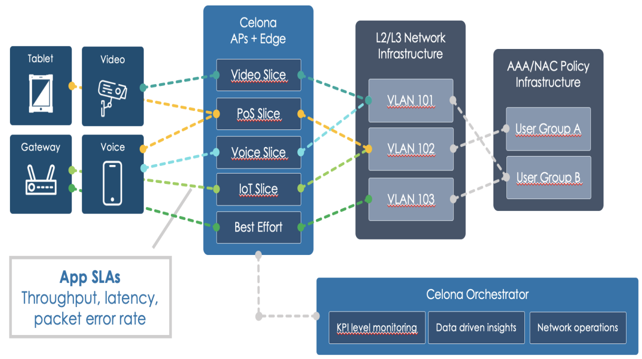

Fig. 2: 5G LAN Micro Slicing Feature.

choices for both consumers and businesses alike. However, the convenience of Wi-Fi can cause interference and collision issues even with the state-of-the-art contention-based channel access mechanisms, especially in densely populated areas. In larger environments, administrators typically segment guest Wi-Fi networks and private networks through different IP subnets and firewall rules to secure corporate data.

When devices move through a large Wi-Fi network, it is possible that mobility issues arise when they transition among different coverages of APs if they are not well tested to operate within enterprise environments. This is because, in a Wi-Fi network, connected devices decide when to roam between APs, to transmit data, and the latency for data transfer[2] could be highly unpredictable under high density and/or traffic congestion. This inherent problem for Wi-Fi is normally unnoticeable to small business environments but intractable for large corporations who look for maximum uptime and performance on the level of enterprise wireless networks. In the WLAN architecture of an end-to-end connected system, each Wi-Fi AP or WLAN is connected to the centralized controller, and the controller is connected through the internet.

IV. Experiment Environment and Configuration

In this section, we discuss the experiment environment and configuration parameters for the WLAN and 5G LAN systems.

A. WLAN Environment and Configurations

In this work, we aim to investigate the performance of WLAN and private LTE/NR networks. We created an open-

[2]If a Wi-Fi client roams from UNII-I to DFS 5GHz band, it needs to verify the database to protect the incumbent, leads to high delay and packet drop.

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air wireless network testbed in the Celona headquarters, USA. The three 802.11ax WLAN APs are deployed on the floor to provide good indoor coverage for mobile devices, laptops, printers, TV, etc., and all these WLAN APs are connected to the centralized controller. Hence, the channel selection, transmission power, and operating bandwidth depend on the optimization algorithms which run on the centralized controller. Please note that we enabled QoS features on WLAN APs. During the time of the WLAN experiment, the controller allocates both UNII-1 and DFS channels 44, 108, and 124 of 40 MHz bandwidth to three WLAN APs. This decision could be based on the other WLAN APs operating on the UNII-1 and UNII-3 which makes the unlicensed channel crowded, and in-turn leads to some channel allocation on the DFS band. Also, the transmission power allocation on the channel varies based on the WLAN band. In our experiment, we observed 15 dBm transmission power for 44 and 48, 40 MHz channel, 15 dBm transmission power for 108 and 112, 40 MHz channel, and 17 dBm transmission power for 124 and 128, 40 MHz channel. The detailed experiment parameters for the WLAN experiment is described in Table. I.

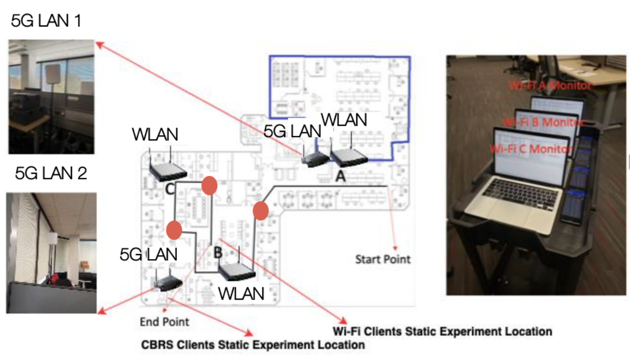

Fig. 3: WLAN and 5G LAN Experiment Setup and Floor Plan.

B. 5G LAN Environment and Configuration

To cover the entire floor with good signal coverage we deployed 2 5G LAN APs[3] on the floor. Each AP is connected to the LAN switches which in turn connects to our closer 5G core (5GC) edge network. We configured each AP with 40 MHz bandwidth of 5G LAN channels which SAS allocated at the time of request grant. When the user moves from one 5G LAN AP to another, the handover algorithm will automatically move the UE flow (Seamless flow with no packet drop, jitter, or latency) to the neighboring 5G LAN AP. The detailed experiment parameters for the 5G LAN experiment as described in Table. II.

C. Traffic Environment: TCP Ipref and Ping Application

The Downlink (DL) and Uplink (UL) ipref traffic goes through our own deployed server (in the 5GC software) to avoid any other additional overhead delay on the backhaul network. Both the DL and UL traffic is TCP, we load the network by enabling multiple TCP connections (*i.e.,* 60) over the ipref. This emulates the scenarios from 25 to 30 UE scenarios with 1 DL 1 UL or 2 DL 2 UL devices. The ping packets are transmitted in the interval of 10 ms and the time to live is 64 hops with the ICMP packet mode. The timeout duration of the ping packet in the experiment is 1000 ms.

[3] 5G LAN AP refers to LTE eNB small cell that runs with LTE release 14

V. Experimental Setup for Static and Mobility

A. Static Experiment Setup

We conduct a static experiment, where all WLAN clients are in the good signal strength region. Since all the clients are operating within unlicensed spectrum. Hence, there exists a lot of contentions for the medium and collisions on the channel. By definition, with Wi-Fi-based WLAN, there will be more control (ACK and NACK packets) and management (beacons, probe, association, authentication). In dense WLAN client deployments, we can expect 60-70% [6] of the air-medium with control and management packets. This gives only less chance for data frame transmission. Fig. 4 shows the management and data frames in the static location. In this scenario, all the Google Pixel devices are in one location *i.e.,* static close to the WLAN AP B coverage region (as shown in Fig. 2), hence we observe more active packet transmissions.

Within the 5G LAN, all the band 48 supported clients are deployed in the good coverage signal of 5G LAN APs (*i.e.,* 5G LAN AP1 & AP2 as shown in Fig. 3). The 5G LAN APs are configured with micro-slicing features, where Celona orchestrate can allocate dedicated slices of resources to guarantee the specific requirement for 5G LAN devices (for example latency of the sensitive device group) and still allow mix traffic transmissions on the air medium. In our experiment, we configured the ping traffic as real-time delay-sensitive with high priority user.

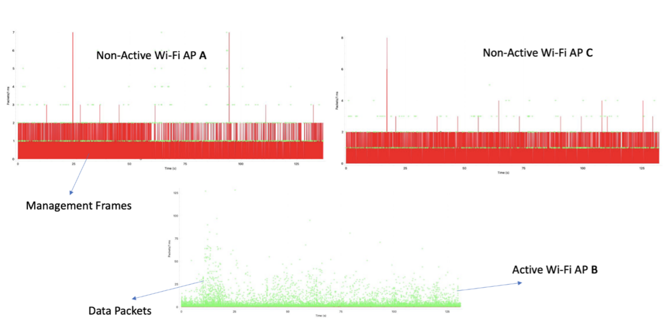

Fig. 4: Static: Management and Data Frames.

B. Mobility Experiment Setup

In case of mobility, the WLAN roaming mechanism is based on a break before make mechanism and could lead to more dropped packets or an increase in latency during handover from one WLAN AP to another WLAN AP. In the 5G LAN system, the handover mechanism is make before break and it is more efficient in mobility with low packet drop rate. Fig. 5 shows the mobility experiment path throughout the entire experiment, within which all devices have connectivity

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TABLE III: Experiment Test Cases

Scenarios	Description
1 Ping	Only one UE running the ping test
5 Ping	Five UEs start the ping test (Approx. at the same time)
1 DL 1 Ping	All two UE traffics (DL, Ping) running iperf and ping on the air
1 UL 1 Ping	All two UE traffics (UL, Ping) running iperf and ping on the air
1 DL 1 UL 1 Ping	All three UE traffics (DL, UL, Ping) running iperf and ping on the air
2 DL 1 Ping	All three UE traffics (2 DL, Ping) running iperf and ping on the air
2 UL 1 Ping	All three UE traffics (2 UL, Ping) running iperf and ping on the air
2 DL 2 UL 1 Ping	All five UE traffics (2DL, 2UL, 1Ping) running iperf and ping on the air

on all three WLAN APs: A, B, and C. In our setup, the Wireshark scans all three WLAN AP channels and Fig. 5 shows the mobility scenario of management and data frames for WLAN channels A, B, and C monitoring. The reason for seeing more packets on WLAN channel B is due to more journey paths on B coverage (as shown in Fig. 3).

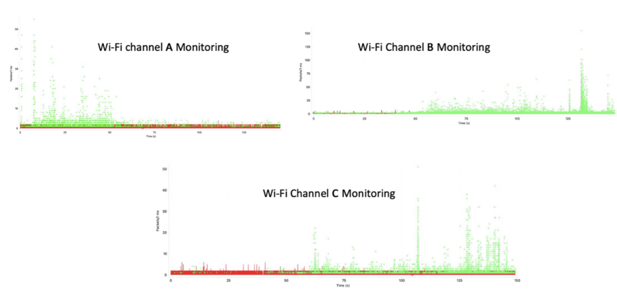

Fig. 5: Mobility: Management and Data Frames.

VI. Experiment Result Discussion

A. Ping Result Discussion

In this setup, we ran ping test to measure latency performance for CBRS and Wi-Fi. As the load increases, we notice an increase in WLAN latency and packet drop rate. There was more contention and collision (UL and DL transmission) in the WLAN CSMA protocol. Whereas, in the 5G LAN network, scheduling occurs for the users based on QCI and fairness on a slot basis. In addition, the Micro-Slicing features enabled at the 5G LAN AP guarantee the dedicated bearer establishment to maintain the QoS for the delay critical traffic (for example Ping).

As shown in Fig. 7, each bar can be constructed as a pair of (x, y), where x and y represent the number of pings and the corresponding metric of interest such as average latency, jitter, and packet drop rate respectively. Note that each sub-figure collects $n = 8$ data pairs for each scenario such as WLAN static, 5G LAN static etc. As such, polynomial interpolation can be exploited to quantify the difference between the 5G LAN and Wi-Fi in terms of these three metrics. According to Interpolation theorem [7], there exist a unique polynomial of minimal of degree at most n that interpolates the $n+1$ data points $(x_0, y_0), \ \ldots, (x_{n-1}, y_{n-1})$, *i.e.,* $p(x) = a_n x^n + \cdots + a_1 * x + a_0$. Substituting this into the interpolation equations $p(x_j) = y_j$, we get a system of linear equations that can be further written in matrix form as follows:

$$\begin{bmatrix} x_0^n & x_0^{n-1} & \ldots & x_0 & 1 \\ x_1^n & x_1^{n-1} & \ldots & x_1 & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_n^n & x_n^{n-1} & \ldots & x_n & 1 \end{bmatrix} \begin{bmatrix} a_n \\ a_{n-1} \\ \vdots \\ a_0 \end{bmatrix} = \begin{bmatrix} y_0 \\ y_1 \\ \vdots \\ y_n \end{bmatrix} \tag{3}$$

that can also be expressed as $\mathbf{X}]\mathbf{a} = \mathbf{y}$. The matrix $\mathbf{X}$ is the well-known Vandermonde matrix that is known to be invertible, *i.e.,* full rank matrix. Therefore, we can obtain a unique variable of interest $\mathbf{a} = \mathbf{X}^{-1}\mathbf{Y}$. Denote the interpolation equations of WLAN state, WLAN mobility, 5G LAN static, and 5G LAN mobility as $p_1(x)$, $p_2(x)$, $p_3(x)$, and $p_4(x)$. To quantify the latency, jitter or packet drop rate difference between WLAN static and 5G LAN static, we have

$$\zeta = \frac{\deg(p_i(x))}{\deg(p_j(x))}, \tag{4}$$

where $\deg(\bullet)$ is a function that returns the highest order of the polynomial.

Fig. 6 (a) shows the latency comparison of 5G LAN and WLAN for different test cases as shown in Table III. In the initial single ping experiment, the WLAN has less latency but as the load increase, there is an inconsistency in the unlicensed spectrum, which leads to more delay to the connected user. Similarly, Fig. 6 (b) shows the impact of jitter on both 5G LAN and WLAN systems. All these latency and jitter has an. impact on the packet drop in the system as shown in Fig. 6 (c). The magnitude of $\zeta = 3$ in Fig. 6 (a), (b), and $\zeta = 4$ in (c) shows that WLAN is worse than 5G LAN by the order of 3 in terms of average latency, jitter, and order of 4 in terms of packet drop rate.

In a realistic warehouse deployment scenario, we expect more load and contention on the unlicensed spectrum, which leads to more latency, *i.e.,* close to 700 to 1000 ms (from our observation). The packet drop rate of the WLAN system increases as the load increases because, in the mobility scenario, the WLAN drops more packets due to being client-controlled. Also, if the WLAN AP operates on the DFS band, then the handover is challenging compared to the other UNII bands.

On the other hand, the 5G LAN network is an infrastructure-based control and constantly takes measurement feedback from the UEs on the order of milliseconds. This helps to make the right choice of when to make the handover decision. As for WLAN, the transmission opportunity (TXOP) is higher (*i.e.,* 6 ms for A-MPDU enabled system) compared to real-time ping traffic (*i.e.,* 2 ms), and Ping traffic needs more frequent opportunities to pass through the air medium. In WLAN, when the AP is wholly occupied or loaded in each (traffic bucket) Queue because of no frequent access to the medium, then the real-time ping traffic (in intervals of ms) cannot be guaranteed due to late transmission or time-out packets.

In WLAN, multiple parallel Transmission Control Protocol (TCP) streams, the downlink, and uplink transmission are based on the CSMA protocol. If the UE does not get an opportunity to transmit the uplink ACK packet to the WLAN AP, then the WLAN AP assumes the ACK packets got lost or dropped. In 5G LAN, downlink and uplink are implemented on slot-based transmission, *i.e.,* time division duplex (TDD). Hence there is no contention or delay in the uplink ACK packet transmission compared to the WLAN system. Also, in 5G LAN, due to the interference-free frequency channel, there is no contention on the spectrum.

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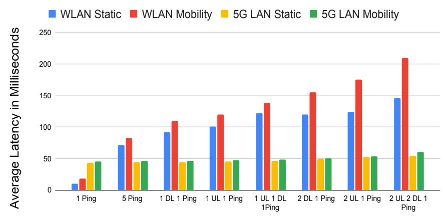
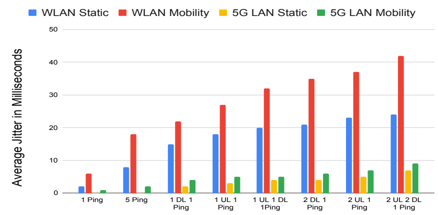
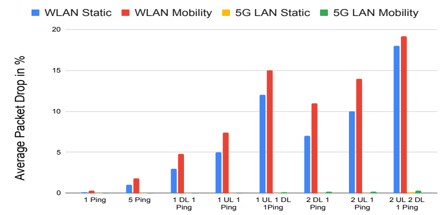


(a) Latency in ms

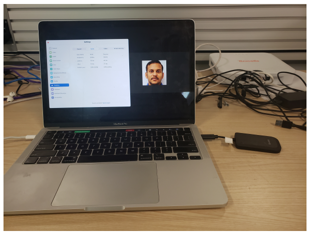


(b) Jitter in ms

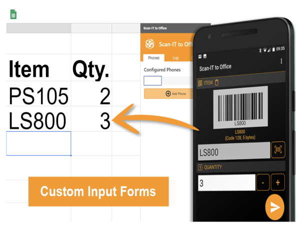


(c) Packet Drop in %

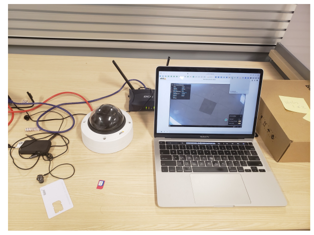
Fig. 6: *Comparison of 5G LAN and WLAN in Latency, Jitter and Packet Drop*



(a) Zoom



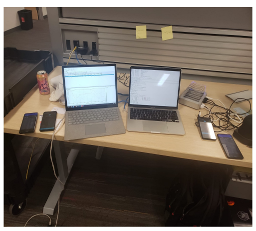
(b) Barcode



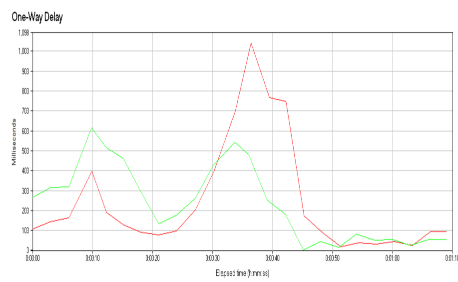
(c) 5G LAN Camera

(d) WLAN Camera

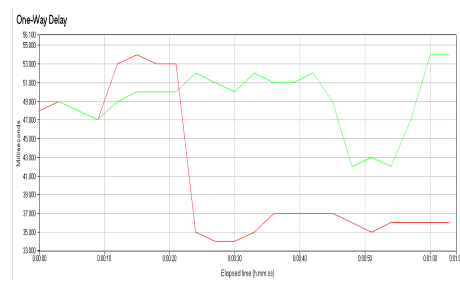
Fig. 7: *Zoom, Barcode and Camera Performance on WLAN and 5G LAN*



(a) VoIP Exp. Setup



(b) WLAN VoIP Latency



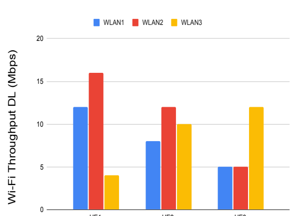
(c) 5G LAN VoIP Latency

Fig. 8: *VoIP Performance on WLAN and 5G LAN*

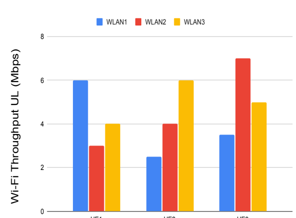
TABLE IV: Different Usecase Performance between WLAN and 5G LAN

APPs	**Unloaded Static**		**Loaded Static**		**Unloaded Mobility**		**Loaded Mobility**	
	WLAN	5G LAN	WLAN	5G LAN	WLAN	5G LAN	WLAN	5G LAN
Zoom	OK	Good	Bad	Good	OK	Good	Bad	Good
Barcode	Good	Good	Bad	Good	OK	Good	Bad	Good
VoIP	Good	Good	Bad	Good	Bad	Good	Bad	Good
Camera	OK	Good	Bad	Good	Bad	Good	Bad	Good

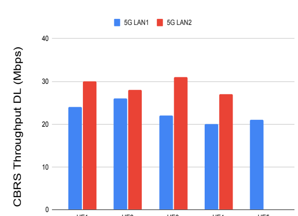
Score: Bad → 1-3, OK → 4-7, Good → 8-10



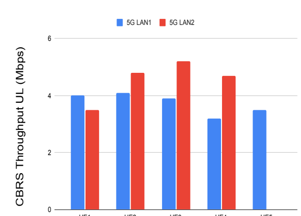
(a) WLAN DL



(b) WLAN UL



(c) 5G LAN DL



(d) 5G LAN UL

Fig. 9: *Average Throughput (Mbps) for WLAN (3 UEs per WLAN) and 5G LAN (5 UEs per 5G LAN 1 and 4 UES per 5G LAN 2)*

A dedicated Micro Slicing feature is enabled to guarantee the delay-sensitive traffic. The scheduling algorithm at the MAC layer (per TTI basis) efficiently schedules the priority and non-priority traffic, which makes the radio link control (RLC) buffer without overflow; hence, there is no need to drop the packets in the 5G LAN system.

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B. Use-cases Result Discussions

In enterprise deployment, we expect the real-time traffic such as cameras, zoom, bar-code scanners, VoIP, etc. to run on both cellular and Wi-Fi system. In this section, we discuss the traffic behavior or characteristics and performance of different use case. Table. IV depicts the impact of different use cases on WLAN and 5G LAN networks. We tested with static and mobility scenarios for the loaded and un-loaded scenarios. In the static scenario, all the WLAN/5G LAN clients are close to the APs. We observed that the WLAN network works better in the unloaded scenario than in the loaded scenario. **Zoom Call:** From the zoom call tests, all the experiments are performed using a laptop client. For CBRS connectivity, the laptop with Quanta dongle acts as a 5G client connected to 5G LAN system as shown in Fig. 7 (a). Similarly for WLAN experiment, the laptop acts as a Wi-Fi client and connect to the WLAN AP. The WLAN WMM and 5G LAN micro-slicing features were enabled for zoom application. In the zoom application setting, the statistics option allowed us to explore the important parameters such as latency, jitter and packet loss for the real-time traffic. In this experiment, both audio and video transmissions are enabled between the WLAN/5G LAN clients in Zoom live session. As the network load increases, *Zoom* call latency, jitter, and packet drop become very high (scaled from 1 to 10) for WLAN. **Barcode Scanner:** In this experiment, we used Scan-IT to Office application for testing as shown in Fig. 7 (b). This application has smart cloud services which scans the barcode and insert the data in real-time into excel spreadsheets. The total number of bar-code scanning performed using the mobile scanner is 10. Each bar-code is scanned in the interval of 1 sec. The expected outcome at the end of 10 sec in both WLAN and 5G LAN networks is 10. When the load increases, the number of successful scans within a period goes down for WLAN. **VoIP:** In this experiment, we used Chariot Keysight voice call application as shown in Fig. 8 (a). The 5G LAN AP operates on (20 + 20) MHz configuration and WLAN AP operates on DFS 40 MHz spectrum. The two google pixel phone is used for VOIP call testing. In parallel to the VOIP call, the iperf UL and DL traffic is running during the experiment. For the loaded scenario, the WLAN MCOT achieves 1.5 with high latency as shown in Fig. 8 (b), and the 5G LAN reaches close to 4 with low latency as shown in Fig. 8 (c). Even with only one UL traffic on the air leads to poor VoIP quality in WLAN system. **Camera:** In this setup, the CPE device is connected to a 5G LAN through CBRS spectrum, and the camera AXIS is connected via CPE as shown in Fig. 7 (c). Similarly, the camera is connected via WLAN as shown in Fig. 7 (d). In this scenario, the camera transmitted with the frame rate of 30 FPS and encoded scheme as H.264. We utilized Wireshark tool to capture at the background during the active frame transmission and we observed more dropped frames in the WLAN system compared to 5G LAN, when the images are buffered and encoded.

C. Capacity Performance Results

In this scenario, three WLAN APs are configured to the best channel *i.e.,* DFS 40 MHz determined by the centralized controller. The two 5G LAN AP operates on the different frequencies of 40 MHz (20 + 20). Hence, there is no co-channel interference. The total number of devices in this setup is 9. Each WLAN AP has three WLAN clients associated so there is a total of 9 WLAN clients. Similarly, on the 5G LAN side, one 5G LAN AP has 5 clients, and the other one with 4 clients. As the load increases, the 5G LAN system can allocate the packet more reliably than the WLAN system. As the load increases, the performance on the WLAN network is not stable compared to the 5G LAN network as shown in Fig. 9(a), 9(b), 9(c) and 9(d). In 5G LAN, the throughput is divided more equally among UEs because of the TDD scheduling mechanism. In WLAN, throughput on the system varied based on the contention among the STAs or WLAN clients and the throughput is not as equally shared as 5G LAN for UEs.

VII. Conclusion

In this work, we showed the first commercial measurement result discussion on Wi-Fi (WLAN) and cellular 5G LAN network. Overall, the WLAN system is susceptible to delay-sensitive applications such as Zoom, Scanner, VoIP and Camera, leading to high packet drop rate and latency since QoS mechanism in Wi-Fi is statistical instead of deterministic. When the traffic or load increases, the WLAN system cannot guarantee a fair share of radio resources among the connected users. On the contrary, 5G LAN utilizes an interference-free spectrum, TDD-based scheduling, and Micro-Slicing features that play a pivotal role in enhancing performance. Hence, the 5G LAN system can achieve the minimum latency with no packet drop and a fair share of radio resources.

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