Battery Life: Performance Analysis and Comparison between Wi-Fi, CBRS, and Macro Deployment System

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***Abstract*—In this study, we analyze the performance of the IEEE 802.11 Wi-Fi Wireless Local-area Network (WLAN), 3GPP 5G LAN (*i.e.,* CBRS), and 3GPP Macro networks in terms of battery efficiency. For the delay-sensitive application running on Wi-Fi, we observed a significant increase in the battery drain. This is mainly due to contention on the unlicensed spectrum medium for packet transmission. On the other hand, devices running on 5G LAN solved consistently low battery drain due to interference-free spectrum channel and efficient allocation of radio resources at MAC scheduling. In addition, in the 5G LAN network, the Celona MicroSlicing feature guarantees precise resource allocation for delay-sensitive applications. In the end, comparing the Macro network, where the base station is at a far distance; the UE or client needs to transmit at high power, which eventually draining battery significantly compared to the CBRS system.**

Keywords: CBRS, Unlicensed, Wi-Fi, Private and Network, Macro Network, Battery Consumption.

I. Introduction

Cell phone battery life [1] [2] has been a fundamental design consideration since the first mobile devices which where introduced in the 1970s. Mobile services at that time only focused on voice; therefore, the problem from a system design perspective often boiled down to finding best-of-breed components [3] (e.g., amplifiers and signal processors) that optimized power while not sacrificing size. However, today's cell phones support a wide array of services beyond voice telephony, therefore battery life optimization [4] [5] is considered vital for each of these multitude of services. Optimizing battery life for internet usage is a challenging problem than optimization for voice telephony or audio and video playback. On the other side, increased traffic (like YouTube, WhatsApp, iMessage, and FaceTime) demands technology from generation to generation, such as Wi-Fi 802.11 ac to ax and LTE 4G to NR 5G to improve the data rate with less latency. Hence, optimizing the battery life for each technology with constraints to the application is crucial. If the battery power drains so much on a mobile device, laptop, or iPad, it significantly affects the business's success.

The WLAN technology of IEEE 802.11 has proven to be an effective indoor technology for fulfilling mobile users' high data rate requirements. Conversely, cellular operators have emphasized implementing small cells in 4G and 5G technologies in outdoor settings, as DAS-based solutions tend to be costly for local and indoor enterprise deployments. Furthermore, these conventional cellular deployments are typically separate from enterprise LANs. The recent release of the Citizenship Broadband Radio System (CBRS [6], [7]) has provided a locally available clean spectrum, gaining more attraction for private deployments in the enterprise scenario. This spectrum is primarily used by military and radar communication, and it is free to access when there is no incumbent nearby. The technology has a total bandwidth of 150 MHz, comprising 15 channels with 10 MHz per channel. The radio must communicate its requirements regarding transmission power, indoor or outdoor, bandwidth, channel, and operating frequency with the initial Base Station (BS) operation's 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 the current scenario, most devices can support cellular and Wi-Fi interfaces. In cellular, the device is capable of operating on licensed spectrum (low, mid, and high), unlicensed spectrum (Licensed Assisted Access (LAA)), and shared spectrum (CBRS). Similarly, the device can use all recent Wi-Fi modes such as 802.11 n, ac, and ax. However, which technology interface demands more energy on battery consumption is unknown.

Despite advancements in cellular and Wi-Fi systems, it is crucial to quantify battery usage when enabling either of these interfaces. This paper presents the results of battery life experiments on a realistic test-bed for Wi-Fi and CBRS. The study aims to compare Wi-Fi (WLAN), cellular 5G LAN network (which operates on the CBRS spectrum), and cellular Macro MNO operator network to understand the behaviour of the battery consumption. The findings suggest that Wi-Fi struggled to maintain good battery life performance for continuous traffic, such as Zoom, compared to the 5G LAN. Moreover, the traditional MNO on the 5G cellular system, where the Macro base stations are deployed outdoors and the UE device or client trying to connect from indoors, exhibited a significantly higher battery drain than the indoor cellular-based CBRS model.

The rest of the paper is organized as follows. Section II presents a brief overview of existing studies on battery power management on smartphones with real applications such as VoIP, Web Services, and Data downloads. Section III explains the necessary background information on WLAN Wi-Fi, LTE and NR Mechanism, and CBRS spectrum model, which helps to understand the experimental section and result conclusions better. Section 1V explains the experimental environment and configuration parameters for Wi-Fi, CBRS, and Macro systems. Section V then evaluates the experimental setup for traffic scenarios, test environment conditions, and test procedures. Experimental results and discussion are presented in Section VI. Finally, Section VII concludes the paper with the main contributions and future work in this area.

II. Related Work

In reality, optimizing the hardware in a mobile phone [8] for a specific internet service is difficult, as many different types of services are available over the internet, like email, video conferencing, and web browsing. Nevertheless, almost all popular internet services that do not require guaranteed quality of service, for example, VoIP, can be delivered as web services in wireless settings. As a result, power optimization in web transport mechanisms is an attractive area of focus for internet power optimization. Authors in [8] observed that the mobile web proxy increases handset battery life for mobile web browsing. By leveraging observed user interaction with web content, we can design the proxy to improve power consumption without sacrificing user experience.

In [9], authors analyzed the performance of battery power management schemes in wireless mobile devices using a queueing theory approach. The authors modeled the battery as a server with finite service capacity and proposed schemes to allow intentional server vacations to exploit the battery recharge effect for increased battery life. In [10], the author proposed a framework called MECH for saving energy and improving the execution time in mobile devices. Also, the proposed MECH, an application from the mobile device, is partitioned into modules or tasks that are offloaded and executed in a mobile device cloud while considering the transmission cost and delay.

Smart Internet Devices (SIDs), particularly Smartphones, are soon turned to be super computers [11], while the restricted battery timing is a focused issue that hinders the steady meeting expectations yield of these devices. In addition, various sensors, high-resolution LCDs, wireless interfaces, GPS, and other advanced features drain the battery quickly, thus, shrinking the operational time. Subsequently, increasing the battery life of SIDs has dire consequences at both hardware and programming levels. Authors in [11] evaluated computational offloading, sending power-intensive processing to remote servers in the cloud and accepting the outcome back on the device's screen.

The antenna design, amplifier, and signal processor are key in the battery drain. If the device is not designed effectively, then it may affect the battery during data transmission over Wi-Fi and cellular using licensed, unlicensed, and shared spectrum. This work compares and quantifies the battery life performance between Wi-Fi, CBRS, and Macro networks.

III. Background

This section explores the background of Wi-Fi, LTE/NR, and CBRS mechanisms. In the later section, this will help us to understand the experimental and result section effectively.

A. WLAN 5GHz Channelization and Access Mechanism

In the present-day scenario, it is observed that Wi-Fi APs are deployed and function on both 2.4 and 5 GHz frequencies. However, spectrum availability is comparatively less, and in 2.4 GHz band the interference is more. Therefore, the WLAN AP is configured on 2.4 and 5 GHz channels, offering more spectrum. The WLAN channelization in the 5 GHz band spans from 5.15 GHz to 5.85 GHz, its known as U-NII bands (Unlicensed National Information Infrastructure), and is divided into three categories each with different usage rules. U-NII-1 and U-NII-3 bands do not have any restrictions on usage except for transmit power limitations. But the unlicensed devices that intend to use U-NII-2 are required to implement Dynamic Frequency Selection (DFS) as radar systems are primary users in the UNII-2 bands. Therefore it is mandatory that the incumbent radar signal must be sensed. If radar is detected at any time, the unlicensed device must vacate that frequency band following a timing protocol. However, since these procedures add complexity to devices, the U-NII-2 band is sparsely used by WLAN.

Although about 560 MHz is available, in the U-NII-1 and U-NII-3 bands, only 160 MHz is heavily used. WLAN uses 20 MHz, 40 MHz, and 80 MHz wide channels. The WLAN, as per the IEEE 802.11 standard, adopts the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) mechanism, which implies that a station can transmit only if the channel is sensed to be idle. If the channel is busy during the DCF Interframe Space (DIFS) sensing period or the station is contending after successful transmission, the station continues to monitor the channel until it senses the channel to be idle for a DIFS period.

B. LTE and 5G NR Mechanism

In the context of Long-Term Evolution (LTE) and 5G New Radio (NR), the reservation of radio resources occurs in a centralized scheduling manner. A Resource Block (RB) is the smallest radio resource unit assigned to a mobile user equipment (UE). An RB is equivalent to a 180 kHz bandwidth in LTE over one subframe's transmission time interval (TTI). It comprises 12 sub-carriers, each with 14 Orthogonal Frequency-Division Multiplexing (OFDM) symbols, amounting to 168 resource elements (REs). NR's sub-carrier spacing (SCS) is 15 KHz or 30 KHz. Before the commencement of the following LTE and NR slot, the eNodeB (eNB) may transmit a reservation signal to reserve the channel if it has already acquired it. The receiver(s) sends an acknowledgement (ACK) if the symbols are decoded successfully after transmission. This allocation of radio resources differs from that of the CSMA based WLAN networks, where all clients contend for the medium for the Up-link (UL) and Down-Link (DL) transmission. In contrast, LTE and NR allocate radio

TABLE I: WLAN Experiment Parameters

Parameter	Value
Number of WLAN APs	4
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	Samsung Xcover Pro
Monitoring S/W	Wireshark

TABLE II: CBRS 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

TABLE III: Macro Experiment Parameters

Parameter	Value
Number of LTE Bands	B2, B4, B12, B41 and B66
Number of NR Bands	N41 and N71
Preferred LTE Band	B66
Preferred NR Band	N71
Operating Bandwidths	20, 15 and 5 MHz
Number of PCI/AP covered	26
Carrier Aggregation	Enabled
Dual Connectivity	Enabled
Spectrum	Licensed

resources to UEs based on the Medium Access Control (MAC) layer's scheduling algorithm, thereby eliminating contention or inefficient spectrum usage issues. This algorithm ensures optimum utilization of all resources to cover UEs due to the centralized scheduling approaches of LTE and NR.

C. CBRS Spectrum Operation Model

The FCC has designated the 3GPP band 48 of radio frequency spectra, which covers 3.5 GHz to 3.7 GHz (i.e., 150 MHz), as the innovation band for new mobile users, despite its initial allocation to the US Department of Defense and the US Navy radar systems. The innovation band, now known as the CBRS band, utilizes LTE/NR technology for private network deployments. It caters to three kinds of users, namely, Tier 1, Incumbent Users (e.g., the Navy radar and satellite system), Tier 2, Priority Access License (PAL) (e.g., private organizations such as hospitals, universities, and factories), and Tier 3, General Authorized Access (GAA) (e.g., unlicensed users such as phones, tablets, laptops, and home routers). Protection against interference from GAA and PAL users is provided to the first-tier incumbent. PALs are assigned to the highest bidders and offer county-by-county coverage. A single PAL consists of a 10 MHz channel within the 3550-3650 MHz band, and the license is renewable every ten years. Given that Tier 3 is of the lowest priority, it permits interference from other GAA users or any other tier.

IV. Experiment Environment and Configuration

The next section will discuss the experimental environment and associated configuration parameters for the WLAN and 5G LAN systems.

A. WLAN Environment and Configurations

This study assesses the effectiveness of WLAN and private LTE/NR networks. For this task, we established an open-air

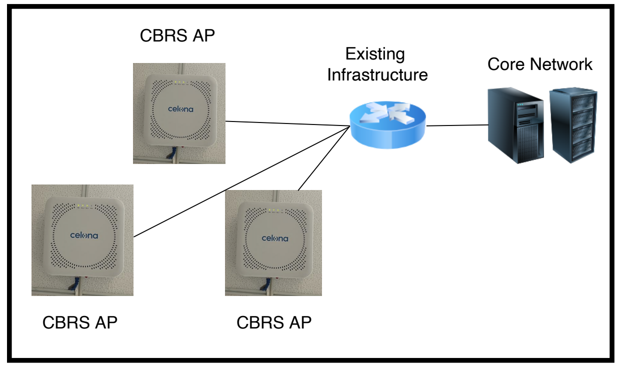
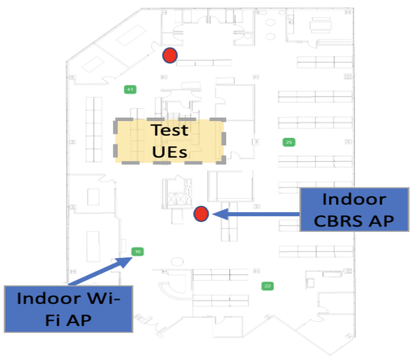


Fig. 1: CBRS Deployment Architecture

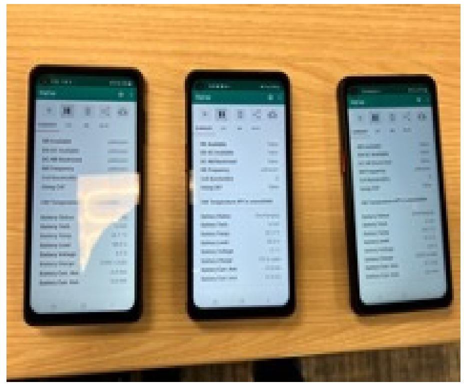
wireless network testbed at the Celona headquarters in the United States. The testbed comprises four 802.11ax WLAN APs strategically positioned to provide optimum indoor coverage for various wireless devices such as laptops, printers, and TVs. All WLAN APs are managed by the centralized controller, responsible for channel selection, transmission power, and operating bandwidth based on its optimization algorithms. It should be noted that QoS features were enabled on the WLAN APs. During the WLAN experiment, the controller assigned both UNII-1 and DFS channels to the four WLAN APs. This decision was made after considering the other WLAN APs utilizing UNII-1 and UNII-3, which led to overcrowding of the unlicensed channel and necessitated channel allocation on the DFS band. Moreover, the power allocation on the channel is subject to variation, depending on the WLAN band. The experiment's comprehensive parameters for the WLAN experiment are presented in Table. I.

B. 5G LAN or CBRS Environment and Configuration

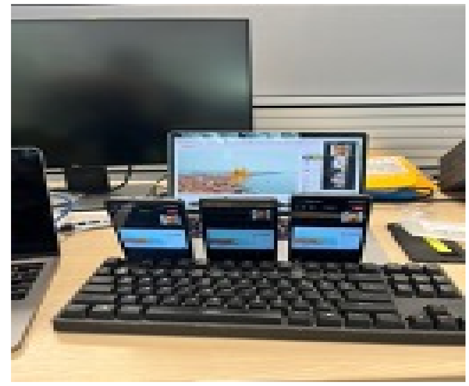
We deployed two 5G Local Area Network Access Points (LAN APs or CBRS APs) on the designated floor to achieve complete floor coverage with optimal indoor cellular signal strength. These APs connect to the LAN switches and the 5G core (5GC) edge network as shown in Fig. 1. We configured each AP with a 40 MHz bandwidth of 5G LAN channels, and the SAS assigned the bandwidth during the request grant process. Celona's handover algorithm automatically transfers the UE flow from one 5G LAN AP to another, ensuring seamless flow with no packet loss, jitter, or latency. In this setup, we also enabled the micro-slicing feature [6] where precise control over resource and service allocation for dif-



(a) Floor Plan



(b) Test UEs - Idle Traffic



(c) Test UEs - Zoom Traffic

Fig. 2: *Wi-Fi and CBRS Floor Plan and Test UE Setup*

ferent groups of applications and devices. The Table II shows detailed configuration of the 5G LAN experiment parameters.

C. Macro MNO Environment

The macro base station deployed by the MNO can operate on 4G LTE and 5G NR spectrum bands. Most of the time, we observed that the primary channel used by the LTE is band 66, and for NR, it is band N71. Depending on the nature of traffic, carrier aggregation is enabled to support the demand of the devices. The bandwidth supported by the operators is in the range of 5, 15, and 20 MHz. We do not have the control to connect to specific PCI. Depending upon the channel selection optimization algorithm, the device was moving from one PCI to another PCI. We noticed no stable connection on a single PCI of the macro network. The detailed macro network parameters are shown in Table III.

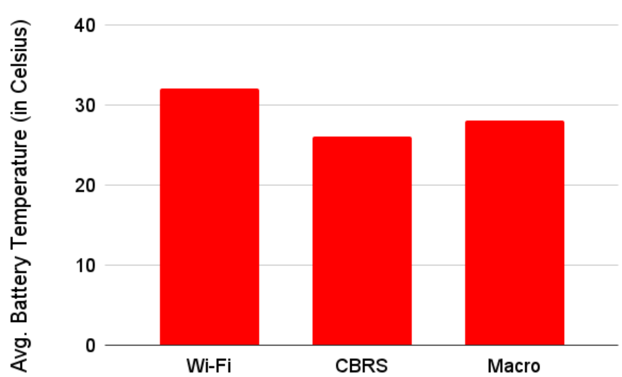


Fig. 3: Battery Temperature

V. Experimental Setup for Battery Performance

In this section, we elaborately discuss the data collection process, experimental test setup, test procedure, and test cases in terms of execution.

A. Data Collection Methodologies

We used an open-source Android app called SigCap[1], developed by research team from the University of Chicago. It can simultaneously collect Global Positioning System (GPS) data and cellular and Wi-Fi information using only the Android API without requiring root access. The SigCap app collects data every 10 seconds, the smallest interval the API allows to conserve power. Each data point we collect consists of the following parameters: channel number, time-stamp, location (GPS latitude and longitude), LTE cell information (Physical Cell Id (PCI)), E-UTRA Absolute Radio Frequency Channel Number (EARFCN), LTE Reference Signal Received Power (RSRP)), Wi-Fi Basic Service Set Identifiers (BSSID), Wi-Fi channel bandwidth, Wi-Fi Received Signal Strength Indicator (RSSI), and Wi-Fi operating mode such as 802.11b, 802.11n, 802.11ac and 802.11 ax. These values are extracted from the phone's modem chip and conform to the standard specifications. In addition, the SigCap app can also collect data on licensed NR and LTE channels and unlicensed and shared spectrum channels.

B. Experiment Test Setup

In this experiment setup, we used three Samsung Xcover pro-UE. In the UE1, Wi-Fi interface is enabled, we connected to the Celona HQ's MIST Wi-Fi[2] network. For the UE2, we connected it to the Celona network using Celona SIM and ensured the Wi-Fi interface was disabled. Finally, we connected the UE3 to Macro MNO operator, and disabled the Wi-Fi interface. All three UEs were tested side-by-side at three different stationary locations inside the Celona HQ. Two different real time test scenarios where conducted on all three devices.

- **Continuous traffic tests:** In this experiment setup, we run the continuous Zoom traffic session with audio and video turned on (with a dynamic background for video), creating an environment where the device/UE continuously uses wireless transmission.
- **Low-duty cycle traffic tests:** In this experiment setup, we want to mimic the scenario where the device is just kept idle *i.e.,* no active data traffic transmission. Only background traffic natively runs on the UEs. This

[1] https://people.cs.uchicago.edu/ muhiqbalcr/sigcap/

[2] The deployed Wi-Fi AP at HQ supports 802.11 ax with standard 6

background traffic includes control packets, Physical Uplink Control Channel (PUCCH) and Physical Downlink Control Channel (PDCCH), and push messages from applications like Messages, Facebook, Instagram, and WhatsApp.

C. Test Environment Condition

To have the choice of experiment location, we conducted two experiments with clients closer to Wi-Fi/CBRS AP and clients to the edge of Wi-Fi/CBRS AP. We observed that when the clients are closer to the Wi-Fi RSSI was in -38 dBm and for CBRS RSRP in - 62 dBm. Similarly, at the edge the Wi-Fi RSSI is -86 dBm, and for CBRS, the RSRP is -105 dBm. All the results are shown below (from Fig. 4 to Fig. 8) the average of all locations. For the macro network, the best case is -102 dBm, and the worst case is -109 dBm.

D. Test Procedure Details

All the tests started with UEs fully charged at 100%. Continuous and low-duty cycle traffic was run for a fixed (e.g., 5 hours) time at Celona HQ. The battery usage was measured using the Android tool Sigcap. Based on battery usage for the fixed period, the battery life of the UE was calculated (e.g., 54% battery usage in 4.5 hours → 8.3 hours battery life). The experiment tests were run during the daytime with ongoing live traffic[3] on the Celona HQ Wi-Fi network, the enterprise CBRS network, and the macro network by other users. We ensured all the test UEs were always active during the continuous traffic tests. Also, during the low-duty traffic tests, all the UEs were in idle state most of the time – extending the battery life. There were variations across different test runs – From Fig. 4 to Fig. 8, we present the average across multiple tests.

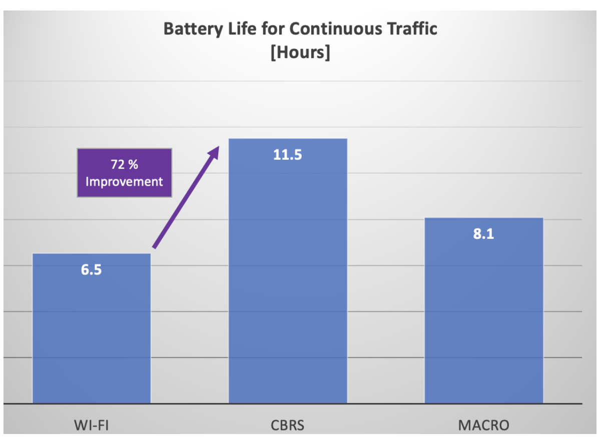


Fig. 4: Static: Battery Life for Continuous Traffic - Zoom

VI. Experiment Result Discussion

This section compares the battery efficiency performance results for Wi-Fi, CBRS, and Macro MNO networks.

[3]The actual employee client devices such as phones and laptops connected to the Wi-Fi and CBRS networks

A. Battery Temperature

Fig. 3 shows the average battery temperature comparison between the Wi-Fi, CBRS, and Macro. For Wi-Fi, the Samsung XCover pro supports Wi-Fi 802.11 a/b/g/n/ac/k/v/r, dual-band, and Wi-Fi Direct. Similarly, it supports all licensed spectrum and CBRS spectrum bands for the cellular. The chipset of this device is Exynos 9611, and the device's CPU is Octa-core (4x2.3 GHz Cortex-A73 & 4x1.7 GHz Cortex-A53). The battery type is Li-Po 4050 mAh. During the experiment, we ensured the device was not connected to other interfaces like Bluetooth or FM/AM radio. The battery temperature depends upon each technology's antenna size, position, and amplifier (like Wi-Fi and Cellular). Based on the observation, we saw a high rise in temperature on the Wi-Fi interface compared to the CBRS and Macro.

B. Static Scenario

In this scenario, all the devices or clients are static, so the RF environments are more stable than the mobility scenario.

1) Battery Life for Continuous Traffic - Zoom: In this test, as shown in Fig. 4, the CBRS AP is configured with the DRX feature to optimize battery life. Based on the results, we observed that Wi-Fi results in lower battery life than CBRS. The low battery life is mainly due to the Over the Air (OTA) transmission. There is more contention on CSMA protocol for packet transmission. Also, we noticed that the Wi-Fi client keeps roaming from one BSSID to another BSSID (in 5 GHz to 2.4 GHz), even in static scenarios. The reason behind this is mainly due to client-based roaming/decision to choose the right AP selection. It varies depending upon the chipset vendor due to interference, number of active users connected, and load with active traffic in DL and UL. However, the CBRS AP is based on the decision for connection establishment and always chooses the best optimal AP. In the CBRS scenario, we did not notice the device moving to another AP or Physical Cell ID (PCI) during the experiment. Also, CBRS follows the scheduling in the TDD slot pattern, where there is a reliable packet transmission in the uplink and downlink directions. Hence, we observed a 72% improvement in CBRS compared to the Wi-Fi network.

On the other hand, the Macro results in lower battery life compared to CBRS. The reason is mainly because the Macro base stations are usually deployed far from the UE by the MNOs, resulting in higher Tx power and a lower data rate. We have also noticed there are more possible PCIs on the licensed spectrum by the MNO, and the device keeps moving from one PCI to another possible PCI (*i.e.,* approximately 42 handovers).

2) Battery Life for Low-duty Traffic: In this scenario, we observed low battery life in Wi-Fi results compared to CBRS (as shown in Fig. 5). The low battery life of devices in the Wi-Fi network is because each short packet (like broadcast or push messages) must be transmitted in an unlicensed medium for successful transmission. Due to this, it wakes the client from idle mode more often than usual. Also, it to re-transmits the packets if there is an unsuccessful transmission. However, in CBRS, the short packets are scheduled with fewer RBs in the TDD slot pattern, and with the DRX feature, therefore it does not need to wake the client more often. Hence, we observed a better battery gain of 32% compared to the Wi-Fi network.

For the Macro network, we could not confirm the DRX feature capability, but the scheduled TDD pattern in the Macro MNO network helps better battery life compared to Wi-Fi. When compared to CBRS, there is still more battery drain in the Macro network. In the test environment, we observed that the devices are in RSRP -102 and -109 dBm at the cell edge scenarios. Due to large distance from the macro base station to the device resulted in higher UE Tx power and lower data rate. Therefore, there are approximately 35 handovers as there was dense availability of PCIs in the Macro network. However, there was no handover observed in the CBRS network.

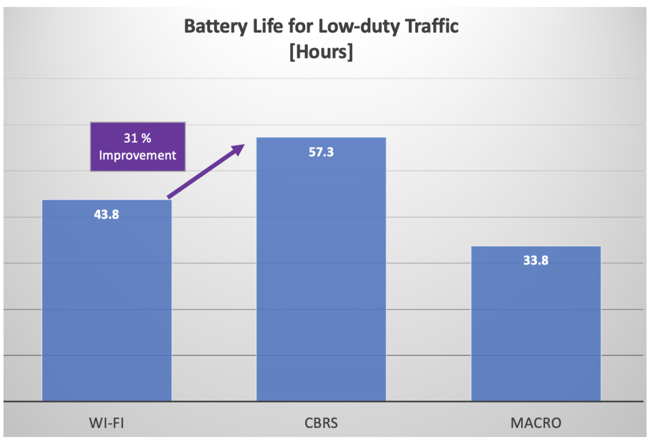


Fig. 5: Static: Battery Life for Low-duty Traffic

C. Mobility Scenario

In this scenario, all the devices or clients are moving, so the RF environments keep varying.

1) Battery Life for Continuous Traffic - Zoom: The Wi-Fi AP beacons are transmitted in the interval of 102.4 ms. In the Wi-Fi scenario, the Samsung device moves from one AP to another. We observed that among the four Wi-Fi APs, one Wi-Fi AP was configured on the UNII-2 band on DFS, and this Wi-Fi AP keeps changing the channel and transmission power due to nearby incumbent radar activities. The Wi-Fi protocol added overhead during the client-based handover process because the roaming mechanism is based on a break-before-make mechanism and could lead to more dropped packets or increased latency during the handover from one Wi-Fi AP to another.

As for Wi-Fi, 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 real-time traffic needs more frequent opportunities to pass through the air medium. In Wi-Fi, when the AP is completely occupied or loaded in each (traffic bucket) Queue because of no frequent access to the medium, the real-time ping traffic (in ms intervals) fails to guarantee service due to late transmission or time-out packets. All these reasons in Wi-Fi lead to more frequent wake-ups for re-transmission packets in the air medium.

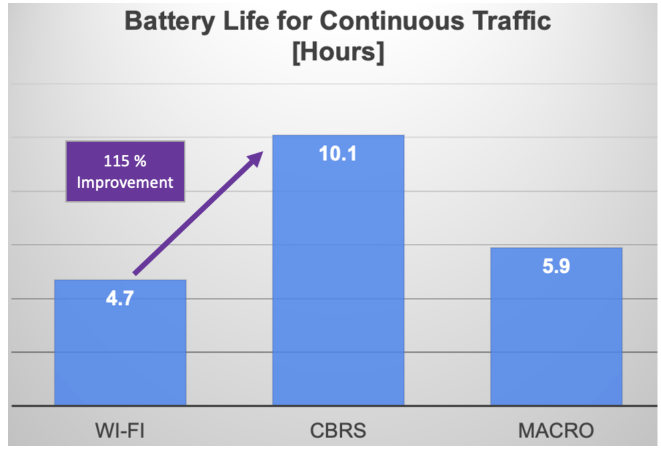


Fig. 6: Mobility: Battery Life for Continuous Traffic - Zoom

In CBRS mobility scenarios, we noticed the handover performance is quicker than Wi-Fi deployment. This infrastructure-based control constantly takes measurement feedback from the UEs in the order of milliseconds, helping UEs to make the right choice of when to make the handover decision[4]. The cellular protocol helps the device transmit the packet more reliably in scheduled TDD frames. On the other side, for Macro deployment, we observed dense EARFCN (PCIs), so it can never have a smooth handover transition with the right choice of PCI selection. Hence, the packet transmission is in low MCS and low bit rate. During mobility, we noticed more coverage holes with an RSRP threshold greater than -115 dBm from the MNO network, eventually leading to more drops and more re-transmission of packets. Overall, it leads to a 115% improvement in CBRS compared to the Wi-Fi network and a 71% improvement in CBRS compared to the Macro network, as shown in Fig. 6.

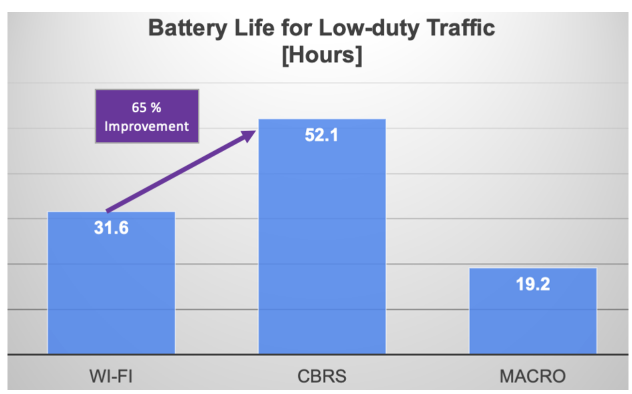
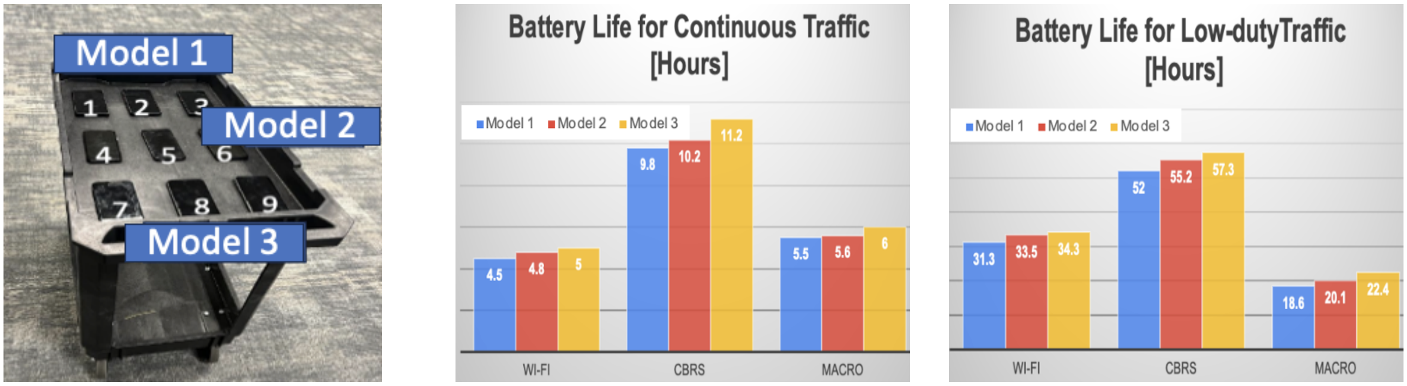


Fig. 7: Mobility: Battery Life for Low-duty Traffic

2) Battery Life for Low-duty Traffic: In this scenario, as shown in Fig. 7, we observed a 65% improvement in CRBS compared to low-duty Wi-Fi traffic. This battery life drop is

[4]The CBRS deployment is inter-frequency assignment and hence the handover is based on RSRP signals with A1, A2 and A4 events



(a) Different Device Vendors *(b) Test UEs - Zoom Traffic* *(c) Test UEs - Idle Traffic*

Fig. 8: *Wi-Fi and CBRS Floor Plan and Test UE Setup*

high compared to the static scenario. In static, the average RF condition is not much changed, and the user can maintain a decent MCS and data rate, which does not need more re-transmission of packets. However, in the mobility scenario, the RF condition varies drastically; though there is no active packet transmission, unnecessary or wrong AP selection leads to additional overhead. Similarly, on the Macro MNO network, we noticed more PCI with dense EARFCN, which leads to more handover (*i.e.,* approximately 92 handovers) triggered in the idle condition. Therefore, the device has a high signaling overhead compared to CBRS. Also, we noticed only eight handovers (during the entire trial route) in the CBRS network.

D. Different Device Comparison

In this section, we compare the battery life between different vendor devices such as Model 1, Model 2, and Model 3 on Wi-Fi, CBRS, and Macro. We considered only a realistic mobility scenario. Fig. 8 (a) shows all the nine devices used in the mobility experiment. UE devices 1, 4, and 7 operate on Wi-Fi technology, UE devices 2, 5, and 8 operate on CBRS, and UE devices 3, 6, and 9 operate on a Macro network. Overall, the battery performance is better on the Model 3 compared to Model 1 and Model 2. The reason could be due to effective antenna design, placement, and amplifier power optimization. In all devices, the CBRS technology has the highest power efficiency compared to Wi-Fi and Macro. The technical reason remains the same as the previous explanation.

VII. Conclusion

In this work, we analyzed and compared the performance of IEEE 802.11 Wi-Fi WLAN, 3GPP 5G LAN (*i.e.,* CBRS), and 3GPP Macro networks concerning battery efficiency. We observed an increase in battery drain for Wi-Fi compared to CBRS and Macro. The battery drain is mainly due to contention on unlicensed spectrum and a more frequent need for transmission for real-time traffic like Zoom. Conversely, the CBRS and Macro network follows TDD-based scheduling, so there is no contention on the medium and resource blocks are allocated reliably for each transmission. Also, the DRX feature on CBRS helps the clients not to wake up more often, leading to less battery drain. In the future, we plan to study and compare the dual SIM operation-based device comparison, roaming between public and private networks and roaming between cellular and Wi-Fi networks.

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