In-Building VOICE Call using Private Network

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***Abstract*—Reliable voice calls (e-911) and connectivity are crucial in emergency situations such as fire, theft, and AMBER alerts. Mobile Network Operator (MNO) base stations can provide outdoor connectivity and voice call options in a smooth and seamless manner. However, most outdoor base station's signals cannot penetrate well indoors due to e-glass and low penetration of 5G (mid and high) frequencies. Since most users are typically indoors, the alternative solution is Wi-Fi, which provides a strong signal footprint indoors. Therefore, the operators collaborated with Wi-Fi vendors to make the cellular VOICE call *i.e.,* Wi-Fi calling. In places like universities, healthcare, and shopping malls, there is a need for dense deployment of Wi-Fi APs, leading to more contention and collision on the unlicensed spectrum medium. Such dense deployments of Wi-Fi APs eventually increase latency and packet drop, leading to poor voice call quality. The entry and rise of private network deployment for mission-critical applications expands the cellular technology indoors. Through private networks, MNOs users can make VOICE call, when outdoor MNO base stations and indoor Wi-Fi signals are poor. Recently, service providers have started using private network infrastructure to route cellular traffic, such as data and VOICE, for their users; this is called Neutral Host (NH). In this work, we compare the VOICE quality on four different technologies (MNO, Wi-Fi, CBRS, and NH) in terms of Mean Score Value, Latency, and Packet Drop.**

I. Introduction

The advancement of Wi-Fi technologies like Wi-Fi 6, 7, and 8 (in the near future) and the link-aggregation on Wi-Fi 7 with 2.4, 5, and 6 GHz [1] improve the throughput of indoor devices drastically. However, there are a lot of new features like Orthogonal Frequency-Division Multiple Access (OFDMA), Basic Service Set (BSS) Coloring, and Quality of Service (QOS) level slicing mechanism on top of Carrier Sense Multiple Access (CSMA) protocol but still a lot of challenges persists to guarantee the QOS on sensitive applications. This is mainly due to the dense deployment of Wi-Fi APs in use-cases like healthcare, super-center, logistics, and warehouse, which demands 1000s of Wi-Fi APs. Most of the time, these APs are deployed close by without proper channel planning and power control. All these lead to more contention and collision on the unlicensed spectrum, which indeed makes the wireless performance, particularly the critical applications, suffer from high latency and packet drop.

On the other hand, the MNO operator's signals are hard to penetrate through the glass material indoors. Most of the 5G NR frequency bands are mid and high, which makes signals from the base station difficult to penetrate indoors, leading to more coverage holes, disconnections on the device, frequent call drops, unsuccessful SMS delivery, and SOS state on the mobile devices. Also, building and deploying Distributed Antenna System (DAS) based infrastructure-like solutions are more expensive as they need running cables all over the buildings. DAS is mostly a single Physical Cell ID (PCI) based solution, where the same frequency is reused among all the small cells inside the building. So even with strong RSRP *i.e.,* -88 dBM, the user or device will experience minimal downlink and uplink throughput performance.

To overcome the MNO coverage problems, operators rely on existing private deployments [2] in those indoor buildings or deploying neutral host-based solutions [3]. Private network deployments have recently increased in several verticals, offering reliable and robust connectivity for mission-critical applications. Similarly, if the customers need better indoor MNO coverage, they rely on a neutral host-based solution, where the MNO traffic is routed over third-party RAN. The most important application that MNOs care about is the voice call (e-911) in indoor regions during emergency situations such as fire, theft, AMBER alert, or personal situations. Currently, there are four methods to serve voice calls indoors.

- *MNO-based Indoor VOICE Call:* In this scenario, users use the existing Macro signal indoors to establish incoming and outgoing voice calls.
- *Wi-Fi based Indoor VOICE Call:* The passthrough mode is enabled on the device to ensure the Session Initiation Protocol (SIP) works reliably so the VOICE call can be routed to existing indoor Wi-Fi APs.
- *Private Network (PN) based Indoor VOICE Call:* If the MNO signal is in SOS mode *i.e.,* no connectivity or if there is a coverage hole from Macro. In addition, the existing Wi-Fi signal is not feasible in those indoor regions. Then, the SIP works reliably to route the VOICE call to the existing indoor Private Network APs.
- *Neutral Host-based Indoor VOICE Call:* In this scenario, we expect the VOIP call to be routed over the third-party small cells RAN the customers deploy to improve indoor coverage.

In this work, we compare VOICE Call performance [4] for MNO, Wi-Fi, PN[1], and NH technologies on different static and mobility scenarios with unloaded and loaded cases. We analyzed or quantified the quality of the voice call in terms of mean opinion score, latency, and packet drop. Table I shows the summary of the voice support options.

[1]In US, the PN is enabled using CBRS technology. Hence we used the term *PN and CBRS* interchangeably throughout the manuscript.

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TABLE I: Summary of Voice Support Options

Parameters	Wi-Fi Calling	CBRS Calling	NH Calling
Type of Voice Traffic	Any MNO	Any MNO	Supported MNOs
Make/Receive MNO calls incl. 911	NA	Yes	Yes (incl. 911 for any MNO)
Typical Users	Employees only	Employees only	Employees only
Other Device/IoT Applications	Yes	Yes	Yes
Device Configuration	Light IT touch required	Light IT touch required	None
Device Requirements	None	Add Celona (e)SIM	None
Type of Phone/Tablet Supported	Any	Any Apple IOS 17.x	Any
Availability	NOW	NOW	NOW

II. Wi-Fi and PN (CBRS): Pros and Cons

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 use by the US Department of Defense, namely US Navy radar systems. However, in 2015, the Federal Communications Commission (FCC) dubbed the 3.5 GHz band the "innovation band" to be opened to new mobile users. 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, 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. Both Wi-Fi & CBRS has their own advantage and disadvantage as described.

- **Spectrum Coordination:** In Wi-Fi, the unlicensed spectrum used by multiple technologies with 563 MHz (plus 1.2 GHz coming in 6 GHz bands). This band also supports incumbent protection on 5 & 6 GHz bands. In CBRS, there is a coordinated spectrum allocation between networks which is ensured by SAS. The total bandwidth is 150 MHz, and it is controlled and centralized by incumbent protection by SAS Environmental Sensing Capability (ESC).
- **Coverage Range:** The Wi-Fi has lower transmit power compared to the CBRS. The Wi-Fi noise floor is based on full channel width (for eg, 20+20, 40+40, 80+80 MHz). The noise floor on Orthogonal Frequency Division Multiplex (OFDM) sub-carriers is 15 KHz.
- **Traffic Handling:** In Wi-Fi, the client and APs are in the nature of distributed contention. The dynamic allocation is possible in either direction. On the other hand, in CBRS, the allocation of radio resources in a scheduled manner. It depends on weighted upload and download profiles.
- **Quality of Service:** The statistical prioritization will happen in Wi-Fi due to the contentious nature of the network. This can be improved by an optional RF loop. In CBRS, the deterministic support of QoS due to scheduling and has mandatory RF feedback loop such as Channel Quality Indication (CQI),Signal-to-Interference-plus-Noise Ratio (SINR), etc.
- **Density Handling:** Wi-Fi supports Single Factor OFDMA, & the legacy OFDM is still Prevalent. The co-channel interference in Wi-Fi is blocked due to the nature of CSMA protocol. On the other hand, CBRS supports dual Factor OFDMA (Freq. Time Domains) and co-channel interference is Non-Blocking.
- **Mobility:** The Wi-Fi needs to have the client off-channel scanning, and the client controls the roaming decisions. But CBRS is based on infrastructure-controlled handover decisions, & its precisely timed.

III. Voice Call Connectivity Options

In this section, we discuss four different options for VOICE calls inside the building.

A. MNO Calling

The indoor user or device connects to Macro base stations deployed outdoors in this scenario. Depending on the location of the base station and the operation of low, mid, or high frequencies, there could be strong or weak signal connectivity. The indoor signal can sometimes be pretty bad with the RSRP range even up to -133 dBm. Regardless, it can allow the user to connect to the base station with a one-bar signal. Hence, in those situations, the voice quality in that wireless link can be pretty bad. In those scenarios, we can expect no incoming calls or the call not being initiated, so it goes to the recorded voice call. Also, the call could connect, but the quality of the call is poor. Unfortunately, this will be more critical in an emergency situation to initiate the e911 call and AMBER alerts.

B. Wi-Fi Callling

For this scenario to work, the device must have the Wi-Fi calling feature enabled, and the MNO must have a coverage hole where the device can reliably go to the SOS state. In this situation, the device will initiate the Session Initiation Protocol (SIP), and the incoming and outgoing voice calls can be routed via Wi-Fi. Unfortunately, hundreds of Wi-Fi APs will be deployed on 2.4 and 5 GHz in most indoor warehouses, hospitals, and super-centers. Most of the time, the configuration chosen by the IT or Controller is 20 and 40

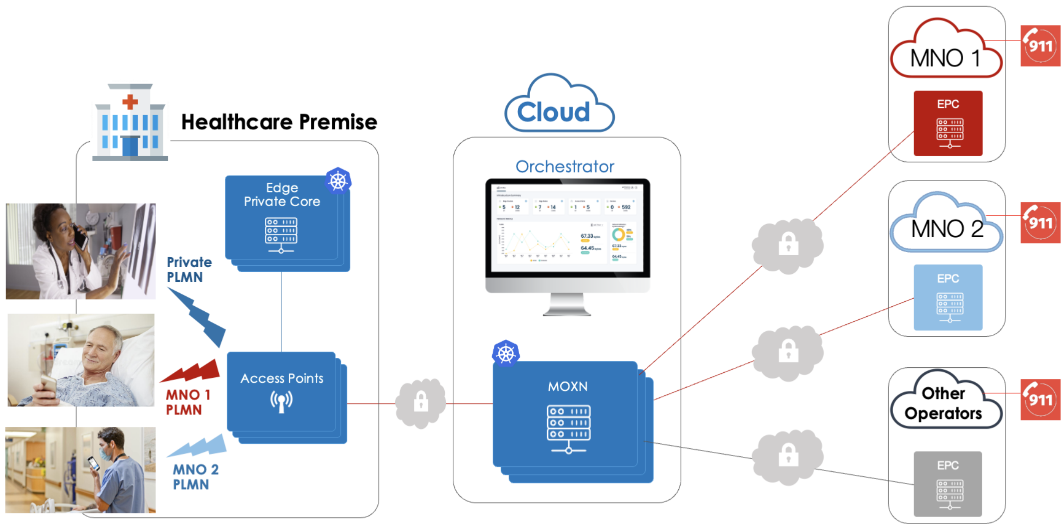


Fig. 1: NH MOXN Gateway Network Architecture

MHz narrow band [5] [6]. This, in turn, increases the range with less number of Wi-Fi APs. On the other hand, with more APs and devices and mixed nature of traffic and applications, there will be contention, collision, and hidden node problems. Hence, Wi-Fi calling may become unreliable in the unlicensed spectrum, leading to poor voice quality.

C. PN or CBRS Calling

If the indoor building is deployed with CBRS APs, then the device will work with every mobile MNO operator in both 4G and 5G, and no opt-in is required. It supports incoming/outgoing voice calls, texts, data, and e911. It works with any iOS 17 Apple Band-48 capable device (iPhone-12* onwards). Even if the device is configured with dual SIM mode, where one slot is MNO SIM and the other is a private network. In the case of a poor MNO with close to zero bar signal or SOS state, the device can reliably make a voice call to the CBRS APs.

D. NH Calling

The NH can act as a seamless extension of the mobile operator network. This requires each operator to opt in, including service integration. The NH can work with any Band-48 capable device (iOS & Android) on 4G and 5G devices. It works for all employees and all guests with zero set-up. This supports incoming/outgoing calls, texts, data, and e911, even for MNOs, not opted-in Transparent Zero touch required per device. When the user walks inside the indoor coverage, the device automatically connects to the B48 network, and the data and voice call packets are routed from the MNO network to the small cell B48 network. Fig. 1 shows the end-to-end connectivity diagram of the NH architecture setup.

IV. Experiment Environment and Configuration

This section discusses the experiment environment configuration parameters and system utilization for the MNO, Wi-Fi, PN (CBRS), and NH systems. In this scenario, we considered the healthcare setup, where devices receive data in both directions in downlink and uplink.

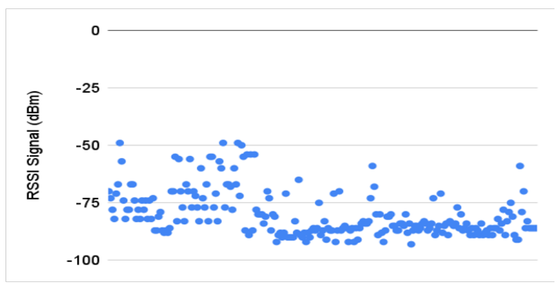


Fig. 2: Wi-Fi Signal Strength RSSI in dBm

A. MNO Environment, Configuration and System Utilization

In this scenario, the Google Pixel mobile device is equipped with a rooted tool *i.e.,* NSG to monitor the detail band information. We observed different bandwidths on licensed spectrum penetration in MNO scenarios, such as 10, 20, and 100 MHz. For indoors, we walked at a consistent speed, and most paths were walked in both directions to limit the impact from the surveyor's body interference. We did both walk tests, and the cart was used at low and high speeds at the indoor locations. The LTE operating bands are B2, B4, B12, B14, B66, and B30. We observed both LTE and NR with the duplex mode of FDD. In LTE, the strong PCI in the experiment region on B2 are 64, 311, and 158; similarly, the strong PCI on B12 are 80, 193, and 250. The weak PCI on B14 and B30 is 184 and 358, and the weak PCI on B4 is 384. The MNO is operating on both low and mid bands in LTE and NR. No NR high band operations were observed near the experiment location. We observed that the MNO signals are weak inside the building, which makes it difficult for the user to load the

TABLE II: CBRS and NH Deployment Parameters

Parameter	Value
Experiment Environment	Indoor
Number of indoor CBRS APs on Floor1	5
Number of Building Floors	3
Mobile iPhones Device Used	13, 14, and 15
Mobile Pixel Device Used	5a, 6a and 7
Mobile Samsung Device Used	S21 and S22
Dongles and Tablets	Quanta and Zebra
Wi-Fi and CBRS AP Placement	Roof Ceiling
Wi-Fi Operating Frequency	2.4 and 5 GHz
CBRS Operating Frequency	3.55 to 3.7 GHz
Mobile devices used	Samsung S21 and Google Pixel
Enabled Celona Micro slicing	Yes
Enabled Wi-Fi QoS	Yes

applications and even make a voice call. Fig. 5 (b) and (c) show the MNO coverage on bands 2 and 4 inside and outside the healthcare building.

B. Wi-Fi Environment, Configurations and System Utilization

In this setup, we don't have access to the Wi-Fi network controller, so we don't provide any system configuration files. The tools used to understand the Wi-Fi Radio Frequency (RF) footprint are Wi-Fi Explorer Pro and Wireshark. Similar to MNO, we walked at a consistent speed, and most paths were walked in both directions to limit the impact from surveyors' body interference. The Wi-Fi cell edges are recorded as -88 dBm as shown in Fig. 2. The three different SSIDs are present, and all are dual-band support. The 2.4 GHz Wi-Fi APs are configured on 20 MHz with the possible channels on 1, 6, and 11, and the basic rates are set at 24 Mbps and the lowest rate set to 12 Mbps. The Wi-Fi 5 GHz is operating on UNII-1 and UNII-3, so there is no DFS active operation on this band; hence, it enables the fast handover. All the Wi-Fi 5 GHz APs are configured to the IEEE Wi-Fi 5 standards, with 20 and 40 MHz bandwidth.

The Wi-Fi clients used in the setup are Samsung, Pixel, and iPhone. The high beacon overhead, which reduced the available bandwidth up to 12%, and also, due to the amount of co-channel interference and quantity of SSIDs in use, a high base channel utilization was observed. In 2.4 GHz, it had up to 41% channel utilization with zero users attached. In 5 GHz, it had up to 18% channel utilization with few users attached.

C. CBRS/NH Environment and Configuration

The PN or CBRS deployment and the connection setup are shown in Fig. 3, where the devices are connected to the private network infrastructure. The frequency planning was constructed based on the Celona Self Organizing Network (SON) algorithm to set the optimal EARFCN and transmission power to reduce the co-channel interference. The PCI allocation algorithm allocates different PCI for each CBRS AP, so there will not be any PCI collision or confusion problem. In this test setup, we used ROHDE & SCHWARZ autonomous mobile network scanner with an external Single Input Single Output (SISO) antenna module to collect the radio signals in terms of PCI, EARFCN, RSRP, RSRQ, and SINR. The Samsung Galaxy S21+ device is used with the Qualipoc setting to collect all PHY, MAC, and Application layer information. The walk and cart test is performed similar to the MNO and Wi-Fi experiment, a custom route developed for the location in the manner that would replicate the real world movements through the indoor health-care building. The collected radio metrics were analyzed using industry-standard post-processing software. The strong RSRP heatmap footprint for CBRS and NH is shown in Fig. 5 (a). Table. II shows the CBRS and NH deployment parameters.

V. Experimental Scenarios and Description

The mobile device is configured with dual SIMs *i.e.,* MNO SIM and private cellular SIM. The tests were run at health-care premises, and the tests were conducted in an indoor environment. We have verified voice and data services over Wi-Fi when we have only Wi-Fi. Also, we have verified voice and data services over PN or CBRS successfully when the MNO service is low *no bar*. [2]. The Wi-Fi calling and data preference configuration need to be turned ON as shown in Fig. 4 (a) and (b). Similarly, the CBRS calling and Wi-Fi calling icons are shown in Fig. 4 (c) and (d).

As the Wi-Fi APs are deployed densely indoor it is important to understand the quality of their Wi-Fi network and would like to have or compare the voice calls go over the PN (CBRS) network whenever the devices are in CBRS coverage. In the future, depending upon the Quality of the voice, the device should prefer the choice of which traffic needs to be routed to which interface guarantees a better user experience.

A. Test Scenarios

The device is enabled with dual SIM on the iPhone. We ensured by default that the private network SIM was the preferred data network and voice for MNO. In the experiment, we have three different test scenarios as listed below

- *Unloaded Base Case:* In this scenario, the devices on the network are transmitting lightweight applications such as short packet live streaming transmission.
- *Less Loaded:* In this scenario, the goal is to load the network with different forms of less downlink and uplink traffic, such as download, streaming, and YouTube.
- *High Loaded:* In this scenario, the device is loaded with high download and upload traffic, streaming, to maximize the capacity of the network.

B. Static Scenario

In the static scenario, all the devices (iPhone, Samsung, Pixel) are placed in the indoor healthcare conference room, as shown in Fig. 6 (a). The goal of this scenario is to ensure all the devices are on the same AP Wi-Fi AP or base stations. In the Wi-Fi scenario, we used a spectrum analyzer app to ensure all the Wi-Fi clients were on the same BSSID. In MNO, NH,

[2]However, when we have both Wi-Fi and PN (CBRS) coverage turned ON, the observation is that both voice and data services go over Wi-Fi instead of PN.

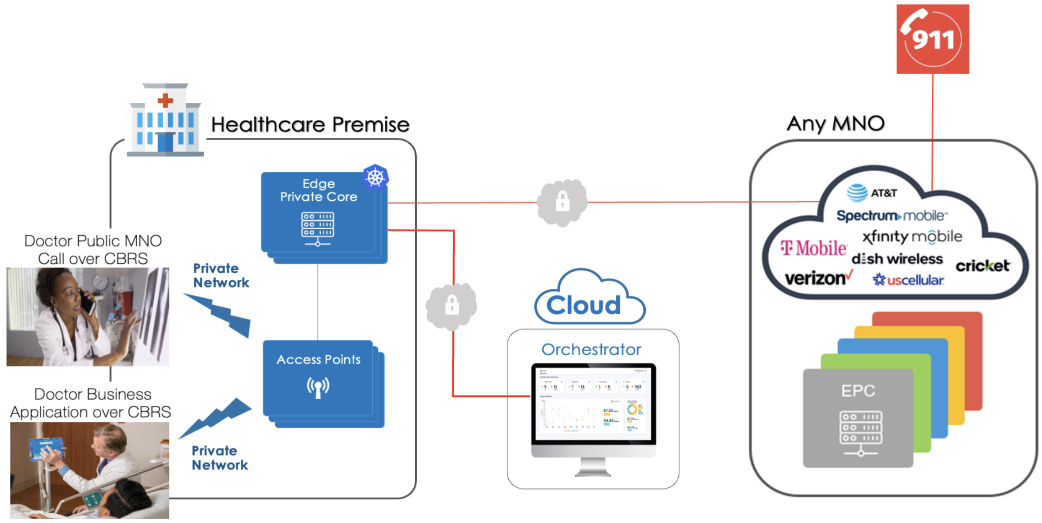
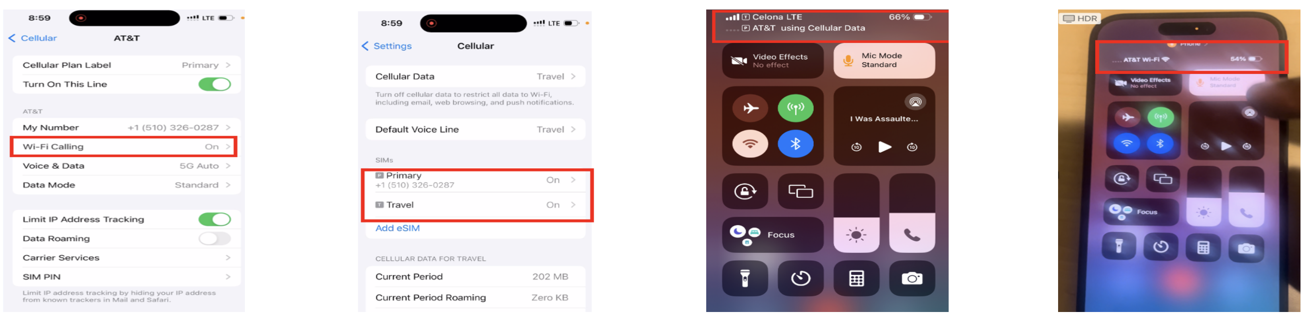
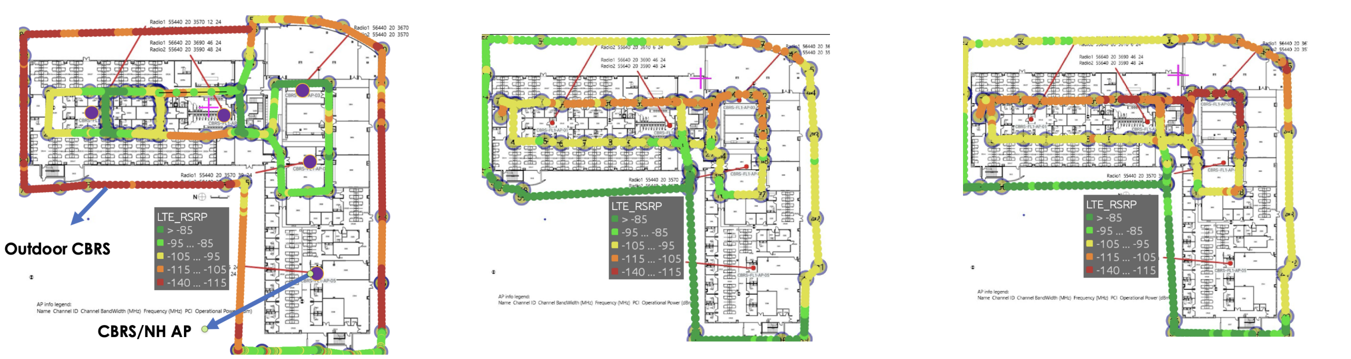


Fig. 3: CBRS Calling Private Network Architecture



(a) Wi-Fi Calling ON *(b) Calling Configuration* *(c) PN or CBRS Calling* *(d) Wi-Fi Calling*

Fig. 4: *PN or CBRS and Wi-Fi Calling Configuration*



(a) CBRS/NH Coverage on Band 48. (b) MNO Coverage on Band 2 (c) MNO Coverage on Band 4

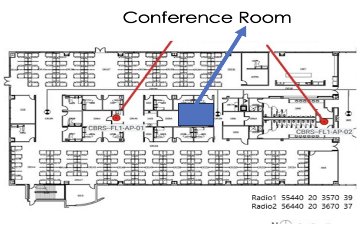
Fig. 5: *CBRS/NH and MNO RSRP HeatMap*

and CBRS scenarios, we lock the phone to a specific PCI so the devices are loaded to one AP or base station. Table III shows the comparison of unloaded and loaded traffic for static scenarios. Fig. 6 (c) shows the number of devices used on the loaded experiment.

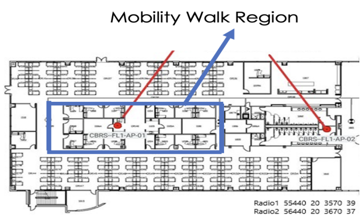
In MNO scenarios, we observed that the RSRP signal footprint inside the building is from -110 to -133 dBm. Most of the time, we noticed that even at the RSRP -133 dBm, the device showed one bar but did not allow the device to go into an SOS state. This eventually leads to three failure scenarios such as (a) the call is not initiated, (b) even if the call is initiated, it goes to the recorded voice call, and (c) the

TABLE III: Different Options of Voice Calling - MNO, Wi-Fi, DAS, CBRS and NH

	Unloaded - Base Case				**Loaded - DL and Streaming**				**Loaded - DL, UL, and Streaming**			
Scenarios	MNO	Wi-Fi	CBRS	NH	MNO	Wi-Fi	CBRS	NH	MNO	Wi-Fi	CBRS	NH
Static	✓	✗	✓	✓	✗	✗	✓	✓	✗	✗	✓	✓
Mobility	✗	✗	✓	✓	✗	✗	✓	✓	✗	✗	✓	✓



(a) Static Experiment Location



(b) Mobility Experiment Location

(c) Loaded Mobile Cart

Fig. 6: *Calling Experiment at Static and Mobility Scenarios*

call went through, but the quality is poor. From the device perspective, holding one bar with poor RSRP leads to 0 UL and 0 DL; eventually, no application traffic is possible.

In the Wi-Fi scenario, more Wi-Fi APs are deployed (literally, each hospital room has one Wi-Fi AP). All these Wi-Fi APs operate on only 20 and 40 MHz in 2.4 and 5 GHz. The more devices with downlink and uplink traffic on the network, the more contention and collision there are on the unlicensed spectrum. Due to the distributed nature of the CSMA protocol, the hidden node problem leads to corrupting the transmission, which in turn leads to more back-off and re-transmission of the packets. Holding the medium for real-time traffic like Zoom and ping (short-packets) will be difficult to transmit in a timely fashion. Similarly, if the medium is not ready to transmit for high-demand traffic, this leads to a buffer overflow, eventually causing more packets to drop at the back-haul. All these factors cause poor user performance, even in static scenarios. Also, for the TCP-based packets, if the ACK is not transmitted in a timely fashion, it leads to more re-transmission of packets in the unlicensed medium.

In CBRS and NH scenarios, the cellular radios are deployed indoors, which follows the scheduling mechanism in the MAC layer of 4G (LTE) and 5G (NR) protocol stack. This makes reliable transmission at intervals of milliseconds in the TDD fashion. Unlike Wi-Fi, all the decisions are made in a centralized fashion with the global knowledge of the topology. Unlike DAS, it's not a single radio with a repeater antenna. Each AP has its own 40 MHz spectrum capacity, which allows users to always have more reliable and high-quality transmission. Hence, there is no difference in the QOS for the Unloaded and loaded scenarios with multiple device transmissions in the air-medium.

C. Mobility Scenario

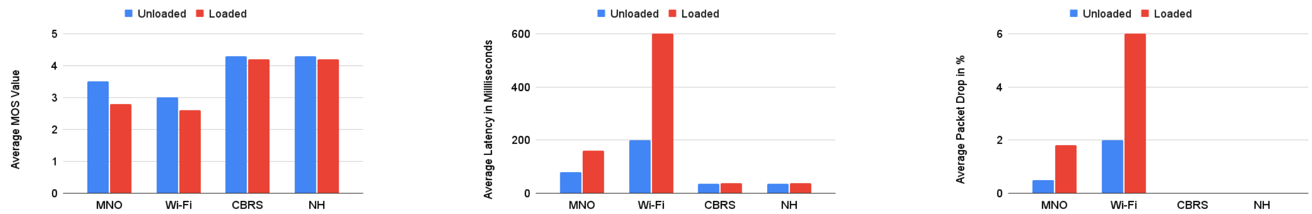
Table III shows the comparison of unloaded and loaded traffic for mobility scenarios. Fig. 6 (b) shows the walk path pattern during the mobility experiment. In the Mobility scenario, the RSRP footprint on the MNO is very low, and this leads to disconnection and poor quality of voice connection. Also, the MNO network is shared by other users near the facilities. Hence, there is a share in the radio resources, which is not dedicated to the facilities where the experiment is conducted. In the Wi-Fi scenario, the handover is based on the client *i.e.,* distributed in nature, where the Wi-Fi client decides based on the AP seen nearby. Hence, depending on the client chipset, we may observe the differences in performance. Overall, the Wi-Fi roaming behavior is challenging during the base-case to the loaded scenarios.

On the other hand, the CBRS and NH radios are deployed indoors with dedicated radio resources for each AP, leading to highly effective spectrum usage. Also, handover in the cellular system is based on centralized decisions. This leads to an effective way to handover from one AP to another AP with seamless transmission of voice calls during the base-case and loaded scenarios.

D. VOICE Quality Measurement

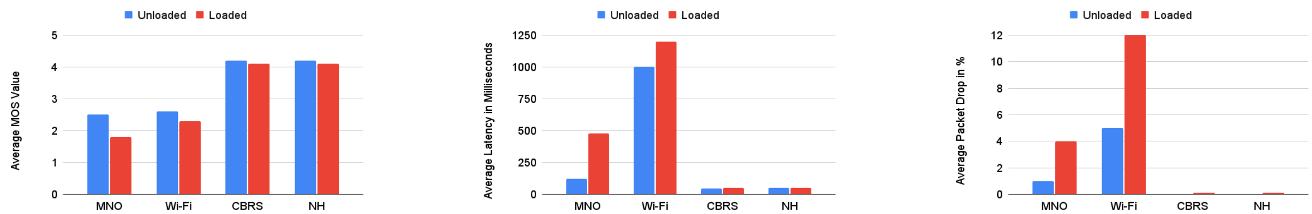
The Mean Opinion Score (MOS) quantifies the Quality of Experience, typically ranging from 1 to 5, with 1 indicating the lowest perceived quality and 5 the highest. The Absolute Category Rating scale, commonly used, maps ratings from Bad to Excellent to numbers between 1 and 5. Voice Quality refers to the overall audio and visual performance experienced during a Voice over Internet or Cellular call, encompassing factors like call clarity, signal strength, delay, echo, and other audio and visual distortions impacting user experience.

Voice Quality can be influenced by factors such as the quality of the internet connection (for Wi-Fi calling), the type of device used, and the supporting network infrastructure. Measuring and monitoring Voice Quality is crucial to ensure effective and efficient communication without audio or visual interruptions.



(a) MOS *(b) Latency* *(c) Packet Drop*

Fig. 7: *Static Scenario - VOICE Quality Experience*



(a) MOS *(b) Latency* *(c) Packet Drop*

Fig. 8: *Mobility Scenario - VOICE Quality Experience*

Voice Quality is typically assessed using a combination of objective and subjective metrics. Common methods for measuring Voice Quality include:

- MOS: The Mean Opinion Score (MOS) is a subjective metric obtained by having a group of people rate the quality of audio samples. It is widely used in the telecommunications industry to assess the quality of voice calls.
- Packet loss rate: This measures the percentage of voice packets lost during transmission. A higher packet loss rate can lead to poor call quality.
- Latency and Jitter: Latency is the delay between when a voice packet is sent and when it is received; high latency can degrade call quality. Jitter, the variation in delay between packets, can also negatively impact call quality when high.

Fig. 7 (a) and Fig. 8 (a) show the average MOS value for static and mobility scenarios for four different technologies, such as MNO, Wi-Fi, CBRS, and NH. The voice quality is poor on Wi-Fi compared to MNO, CBRS, and NH. This could be due to the short packet voice call, which requires more frequent opportunities for an unlicensed spectrum. As the Wi-Fi deployment is more dense and has more contention, there is less opportunity for voice packets. This, in turn, increases the latency of those critical packets, as shown in Fig. 7 (b) and Fig. 8 (b). Also, in the mobility scenario, the break and make handover in the Wi-Fi leads to poor performance on the voice quality, eventually leading to a packet drop, as shown in Fig. 7 (c) and Fig. 8 (c).

On the other hand, in the MNO scenarios, the Macro base stations are deployed outdoors, and the penetration of the signal strength is not strong compared to the CBRS and NH radios, which are deployed indoors. This demands more radio resource allocation for the MNO-connected user indoors. Also, the MNO radios are shared by other outdoor users near the indoor location. This leads to a smaller amount of radio resource allocation. So eventually, voice calls, though they require short packet transmission, with low RSRP and less spectrum, lead to poor MOS, high latency, and packet drop. We observed the VOICE quality on CBRS and NH is good compared to MNO and Wi-Fi static and mobility scenarios.

VI. Conclusion

Ensuring reliable VOICE calls indoors at the time of emergency is crucial. In this work, we enabled the four different technologies *i.e.,* MNO, Wi-Fi, PN CBRS, and NH, which allow the device to perform VOICE calls. We compared the performance of the VOICE quality in terms of MOS, latency, and packet drop. We observed the VOICE quality is good in the CBRS and NH systems compared to MNO and Wi-Fi.

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