A Test-bed Evaluation of DAS, Wi-Fi, Neutral Host and Outdoor Macro

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Abstract—**Indoor wireless connectivity presents significant challenges, particularly in high-density and under-ground basement environments. While advancements in Wi-Fi (6, 7, and beyond) offer increased throughput, inherent limitations related to unlicensed spectrum contention, Wi-Fi client based decision and channel planning hinder guaranteed Quality of Service (QoS). Mobile Network Operator (MNO) signals, especially mid- and high-band 5G frequencies, struggle to penetrate building materials, leading to coverage holes and unreliable connectivity. An MNO-based DAS repeater extends a MNOs coverage by amplifying and redistributing cellular signals within buildings but its limited to outdoor MNO radio bandwidth and capacity. A Neutral Host in CBRS enables multiple MNOs to share a common private cellular infrastructure. It helps reduce deployment costs and improves coverage and capacity in enterprise and public venues. This paper examines and compares four primary indoor connectivity solutions: MNO, Wi-Fi, Neutral Host (NH), and Distributed Antenna Systems (DAS), analyzing their respective Signal Strengths (RSRP, RSSI), SINR, and Throughput. The findings highlight the trade-offs associated with each technology and provide insights into their suitability for various indoor environments.**

I. INTRODUCTION

The demand for reliable indoor wireless connectivity is driven by an increasingly mobile workforce and the proliferation of connected devices. This is particularly acute in environments like healthcare facilities, super-centers, logistics hubs, distrubution center, retails, and warehouses, which can require thousands of access points to meet coverage and capacity needs. While advancements in Wi-Fi technologies, such as Wi-Fi 6, 7, and the forthcoming Wi-Fi 8, promise significant throughput improvements through features like orthogonal frequency-division multiple access (OFDMA) and link aggregation, fundamental challenges persist in guaranteeing Quality of Service (QoS) for sensitive applications. Despite enhancements like Basic Service Set (BSS) coloring and QoS-level slicing mechanisms on top of the Carrier Sense Multiple Access (CSMA) protocol, dense Wi-Fi deployments often suffer from contention and collisions on the unlicensed spectrum. This results in high latency and packet drops, ultimately degrading the performance of critical applications.

Alternatively, relying solely on Mobile Network Operator (MNO) signals for indoor coverage presents its own set of difficulties. The signal penetration of 5G New Radio (NR) frequencies, particularly those in the mid and high bands, is significantly hampered by modern building materials, especially e-glass. This limited penetration results in coverage holes, frequent disconnections, and unreliable service for indoor devices. Addressing these coverage limitations through the deployment of Distributed Antenna Systems (DAS) presents a different set of trade-offs. While DAS can provide enhanced indoor coverage, deployment costs are substantial due to the need for extensive cabling throughout the building. Furthermore, traditional DAS implementations are often based on a single Physical Cell ID (PCI), where the same frequency is reused or repeaters across all small cells within the building. This limits overall system capacity, as users may experience degraded downlink and uplink throughput performance even with strong received signal strength indicator (RSRP).

In response to these challenges, MNOs are increasingly leveraging existing private network deployments utilizing Citizens Broadband Radio Service (CBRS) based shared spectrum model, have gained traction across various verticals, offering robust and reliable connectivity for mission-critical applications. Alternatively, operators may rely on neutral host-based solutions [1, 2], where MNO traffic is routed over a secure (IPSec tunnel) third-party radio access network (RAN) infrastructure to improve indoor coverage (as shown in Fig. 1). This approach allows carriers to extend their reach without significant capital expenditure or infrastructure modifications. This work presents one of the **first real-time measurements** with respect to the performance comparison of DAS, Wi-Fi, Neutral Host and Macro. The remainder of this paper compares MNO, Wi-Fi, CBRS, and DAS technologies, considering key performance parameters including coverage (RSRP), co-channel interference (SINR), and DL/UL throughput performance.

II. SPECTRUM CHARACTERISTICS: WI-FI AND MNO, NH AND DAS

This section introduces the primary mechanism of Wi-Fi and cellular technology (MNO, DAS and NH). We also demonstrate the difference between these two technologies in terms of protocol and mathematical aspects to qualitatively analyze the distributed and centralized properties of the Wi-Fi and Cellular systems, respectively. Please note that the qualitative analysis is also mentioned in the experiment section to justify the results collected from the real Wi-Fi and Cellular deployment setup. Table I shows various wireless connectivity options.

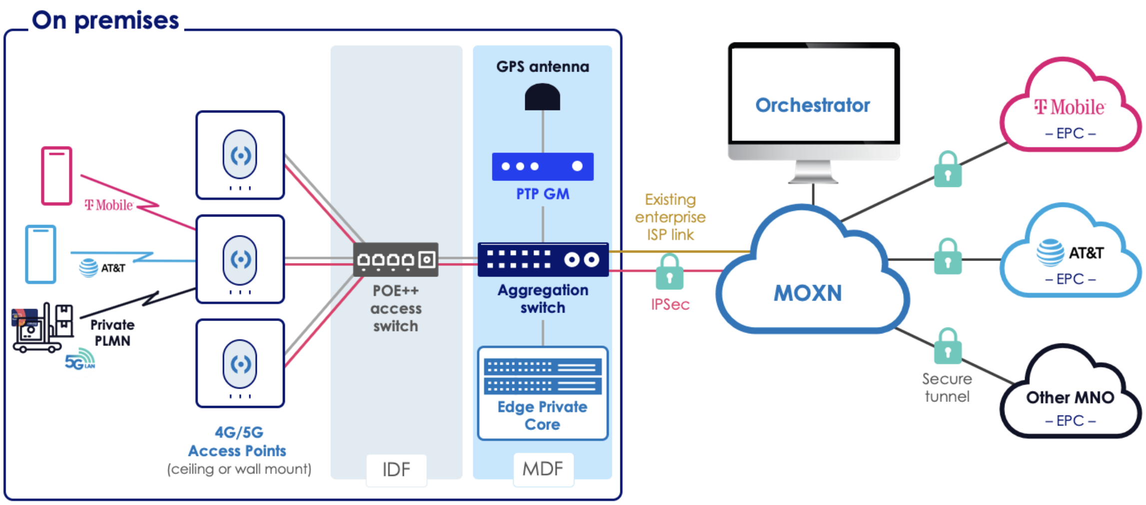

Fig. 1: NH MOXN Gateway End-to-End Network Architecture

A. Wi-Fi 5GHz Channelization and Access Mechanism

In modern wireless deployments, Wi-Fi access points (APs) typically operate over both the 2.4 GHz and 5/6 GHz frequency bands. However, the 2.4 GHz band generally suffers from limited available spectrum and increased interference due to overcrowding. In contrast, the 5/6 GHz band offers a wider range of channels, allowing for better spatial reuse and reduced interference. Accordingly, the Wi-Fi tests conducted in this study were implemented over both 2.4 GHz and 5 GHz channels. Specifically, the 5 GHz band spans from 5.15 GHz to 5.85 GHz, allowing for greater channelization flexibility.

Wi-Fi, as defined in the IEEE 802.11 standard, utilizes the CSMA/CA protocol [3]. Under this protocol, a station may transmit only if the channel is sensed as idle and the station has not just completed a successful transmission. If the channel is busy during the DCF Interframe Space (DIFS) sensing period or if the station is in contention following a successful transmission, the station will continue sensing the channel until it is idle for a DIFS period.

Let us consider a scenario where N stations contend for access to a single channel and each station transmits with probability τ. The probability of a collision occurring is given by:

$$p = 1 - (1-\tau)^{N-1}, \tag{1}$$

where $(1-\tau)^{N-1}$ represents the probability that all other $N-1$ stations remain idle during a time slot. The complement of this event indicates that at least one other station transmits, resulting in a collision.

The transmission probability τ can be expressed as a function of p as follows:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1) + pW(1-(2p)^m)}, \tag{2}$$

where W is the minimum contention window and m is the maximum backoff stage. This expression is derived by summing the steady-state probabilities from the Markov chain model described in [3]. To solve for τ and p, numerical methods such as fixed-point iteration can be applied.

As the number of contending stations N increases, the likelihood of multiple simultaneous transmissions also increases. Consequently, the probability of a successful transmission per time slot, defined as

$$P_s = \frac{N\tau(1-\tau)^{N-1}}{1-(1-\tau)^N}, \tag{3}$$

tends to decrease. This leads to reduced network throughput and a higher collision rate as network congestion rises. To further analyze the packet drop rate attributable to the physical layer, we consider the spectral efficiency $\mathbf{C}$ (in bit/s/Hz) of the operating Wi-Fi channel for user equipment (UE) [4]. As $\mathbf{C}$ increases, the rate at which packets are transmitted from the uplink/downlink buffer improves, assuming a constant successful transmission probability. Conversely, low spectral efficiency reduces the transmission rate, leading to higher buffer occupancy and packet drops. Thus, packet drop rates caused by CSMA/CA-based contention can be exacerbated by poor spectral efficiency in Wi-Fi networks.

B. MNO Mechanism

Unlike Wi-Fi, which relies on a contention-based medium access mechanism using CSMA/CA, LTE and 5G New Radio (NR) utilize centralized scheduling for radio resource management. In Wi-Fi networks, user equipment (UE) must contend for uplink (UL) and downlink (DL) transmissions, often leading to collisions and inefficient spectrum utilization. In contrast, LTE and NR systems allocate resources at the Medium Access Control (MAC) layer through a base station (eNodeB or gNodeB), which assigns resource blocks (RBs) to UEs based on a predefined scheduling algorithm. This approach eliminates contention and ensures efficient utilization of the available spectrum.

Celona's 5G system employs an enhanced version of the *Proportional Fairness* (PF) scheduling algorithm[1]. Let $x(n)$ denote the data rate of UE n, and $\log(x(n))$ represent the corresponding utility. According to the formulation in [5], the PF-optimal solution $x^*(n)$ satisfies the inequality:

$$\sum_{n \in N} \frac{x(n) - x^*(n)}{x^*(n)} \leq 0, \tag{4}$$

which implies that any deviation from the PF-optimal allocation leads to a non-positive aggregate gain in utility. The PF algorithm, as discussed in [6], is proven to asymptotically maximize network throughput while maintaining fairness across UEs.

A significant advantage of PF scheduling is its consideration of both the UE's data buffer size (UL/DL) and its channel spectral efficiency. UEs with higher data rates—either due to more favorable channel conditions ($\mathbf{C}_n$) or larger buffered traffic—receive a proportionally larger share of the radio resources. Conversely, UEs with lower spectral efficiency receive fewer resources, proportionally scaled down. Thus, centralized scheduling ensures no resource is wasted, although the system throughput may still be limited by poor channel quality.

In Celona's CBRS-based NH network deployment, the PF algorithm is used within a utility maximization framework. The average data rate $R_t(n)$ of UE n up to time t over a sliding window of T time slots is defined as:

$$R_t(n) = \left(1 - \frac{1}{T}\right) R_{t-1}(n) + \frac{1}{T} x_{t-1}(n), \tag{5}$$

where $x_{t-1}(n)$ is the instantaneous data rate at time $t-1$. The PF scheduler selects the user n^* that maximizes the following metric:

$$n^* = \arg\max_n \left\{P_t(n)\right\}, \tag{6}$$

with

$$P_t(n) = \frac{C_t(n)}{R_t(n)}, \tag{7}$$

where $C_t(n)$ is the instantaneous spectral efficiency (bit/s/Hz) for UE n at time slot t. The scheduler allocates RBs to UEs in descending order of $P_t(n)$ until all RBs are distributed for the current time slot.

This PF-based scheduling framework enables a balance between maximizing throughput and ensuring fairness, aligning with the performance goals of enterprise 5G networks.

C. NH Spectrum Operation Mode

The NH network in US operates in the 3GPP Band 48, spanning the 3.5 GHz to 3.7 GHz frequency range:

$$f \in [3550, 3700] \text{ MHz}, \tag{8}$$

which provides a total bandwidth of 150 MHz. This spectrum is shared among three distinct tiers of users, defined by the Federal Communications Commission (FCC) to balance protected access with dynamic spectrum sharing.

1) Tier 1: Incumbent Access (IA): Tier 1 consists of federal users such as U.S. Navy radar systems and fixed satellite services. These incumbents have priority access and are protected from interference by all other tiers. That is, interference from Priority Access License (PAL) and General Authorized Access (GAA) users must satisfy:

$$I_{PAL \to IA} = 0, \quad I_{GAA \to IA} = 0, \tag{9}$$

where $I_{X \to Y}$ denotes the interference caused by user class X to user class Y.

2) Tier 2: Priority Access License (PAL): PAL users include private entities such as hospitals, universities, and manufacturing facilities. These licenses are auctioned on a county-by-county basis. Each PAL grants access to a 10 MHz channel within the 3550–3650 MHz range:

$$f_{PAL} \subseteq [3550, 3650] \text{ MHz}, \tag{10}$$

and PALs are assigned in renewable 10-year blocks. PAL users must tolerate interference from Tier 1 users but are protected from GAA users:

$$I_{IA \to PAL} > 0, \quad I_{GAA \to PAL} = 0. \tag{11}$$

3) Tier 3: General Authorized Access (GAA): GAA users include semi-licensed and opportunistic users such as mobile phones, tablets, and home routers. These users can operate across the full B48/N48 band:

$$f_{GAA} \subseteq [3550, 3700] \text{ MHz}, \tag{12}$$

but must tolerate interference from both Tier 1 and Tier 2 users:

$$I_{IA \to GAA} > 0, \quad I_{PAL \to GAA} > 0. \tag{13}$$

Additionally, GAA users must coexist with each other without protection:

$$I_{GAA_i \to GAA_j} > 0, \quad \forall\, i \neq j. \tag{14}$$

D. DAS Spectrum Mechanism and Operation Model

DAS is a network of spatially separated antenna nodes connected to a central signal source, such as a base station or small cell or repeators. It is designed to enhance wireless coverage in environments where macro-cell signals are weak or obstructed, including indoor venues, stadiums, tunnels, and large enterprise buildings.

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[1] Due to privacy and confidentiality constraints, the exact implementation of Celona's MAC scheduler is not disclosed.

TABLE I: Summary of Wireless Connectivity Options - Wi-Fi, MNO, DAS and NH

Parameters	**Wi-Fi**	**MNO**	**NH**	**DAS**
Type of Voice Traffic	Any MNO	Any MNO	Any MNO	Any MNO
Make/Receive MNO calls incl. 911	NA	Yes	Yes (incl. 911 for any MNO)	Yes
Typical Users	Employees only	Employees only	Employees only	Employees only
Other Device/IoT Applications	Yes	Yes	Yes	Yes
Device Configuration	Light IT touch required	None	None	None
Device Requirements	None	None	None	Yes
Type of Phone/Tablet Supported	Any	Any	Any	Any
Availability	NOW	NOW	NOW	NOW

1) Spectrum Mechanism: DAS does not operate on its own independent spectrum. Instead, it retransmits the RF signals of a source network. Depending on the deployment model, the spectrum usage is inherited from:

MNO-based DAS: Uses licensed spectrum owned by Mobile Network Operators (MNOs), typically in LTE/5G bands such as 700 MHz, 1800 MHz, or 2600 MHz.

CBRS-based DAS: Operates in the 3.5–3.7 GHz CBRS band (3GPP Band 48), where spectrum is dynamically managed by the SAS. The total CBRS bandwidth is:

$$B_{CBRS} = 3700 \text{ MHz} - 3550 \text{ MHz} = 150 \text{ MHz}. \tag{15}$$

Hybrid DAS: May support MNO, CBRS, and Wi-Fi simultaneously, combining signals at the head-end and distributing them through the same infrastructure.

2) Spectrum Coordination and Compliance: DAS inherits spectrum responsibilities from its signal source:

MNO DAS: Spectrum is licensed and coordinated by the mobile operator.

CBRS DAS: Spectrum coordination is handled by the SAS, which assigns frequency channels and enforces incumbent protection rules. DAS deployments must operate within authorized limits and ensure:

$$I_{\text{DAS}\to\text{Incumbent}} \leq I_{\text{thresh}}, \tag{16}$$

where I_{thresh} is the interference protection threshold set by SAS or FCC regulations. In this work, we focus on the MNO based DAS using a centralized distribution model. Its performance is governed by physical layout, RF planning, and the constraints of the underlying spectrum mechanism.

III. Wi-Fi, NH, MNO, and DAS: Pros and Cons

Each wireless access technology—Wi-Fi, NH, MNO, and DAS has distinct advantages and limitations, depending on use cases such as enterprise networking, mobility, density, QoS, and spectrum management. A comparative analysis is summarized below:

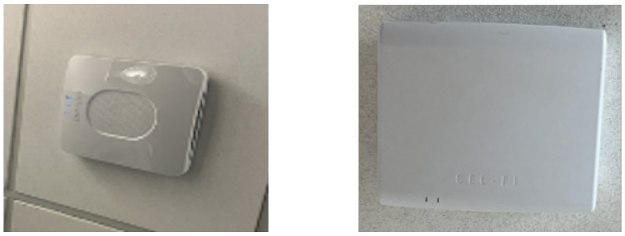
*1) **System Coordination**:* Wi-Fi operates in unlicensed spectrum bands—such as 2.4 GHz, 5 GHz, and the emerging 6 GHz—providing over 1.7 GHz of total bandwidth. However, it lacks centralized coordination, as the spectrum is shared among various technologies and users, leading to potential contention and collision on the un-licensed spectrum medium. MNOs operate exclusively within fully licensed spectrum, granting them centralized control and dedicated access. DAS do not use independent spectrum but rather extend the coverage of an existing MNO licensed spectrum. In contrast, NH systems utilize licensed shared access in the 3.5–3.7 GHz CBRS band (150 MHz), with spectrum managed by the SAS and Environmental Sensing Capability (ESC) to ensure incumbent protection.

*2) **Coverage Range**:* Wi-Fi coverage is typically limited to tens of meters due to its low transmit power and higher noise floor resulting from wide channel bandwidths (20/40/80 MHz), with OFDM subcarriers spaced at 15 kHz. In comparison, NH offers improved coverage through higher transmit power—up to 30 dBm—and reduced interference enabled by scheduled access mechanisms. MNOs deliver broad coverage across indoor, outdoor, and rural areas, supported by high transmit power and exclusive use of licensed spectrum. DAS further enhance indoor coverage by relaying MNO signals within large venues such as stadiums and airports, although the effectiveness of coverage depends heavily on the signal source and overall system design.

*3) **Traffic Handling**:* Wi-Fi uses a distributed contention-based access mechanism (CSMA/CA), where traffic is dynamically allocated but lacks deterministic guarantees, especially under congestion. In contrast, NH networks employ centralized, scheduled radio resource allocation per AP or radio, taking into account weighted uplink and downlink demand profiles to optimize performance. MNOs leverage similar centralized scheduling mechanism to manage uplink and downlink traffic with high reliability and QoS enforcement. DAS are agnostic to traffic scheduling, as they simply relay the signal; the actual traffic management is handled by the host network, whether MNO or any shared spectrum based.

*4) **Quality of Service (QoS)**:* Wi-Fi provides best-effort service with statistical prioritization and limited QoS capabilities, although some optional RF enhancements can improve performance. MNO or NH networks support deterministic QoS through scheduled MAC-layer resource allocation and real-time RF feedback mechanisms, including Channel Quality Indicator (CQI) and Signal-to-Interference-plus-Noise Ratio (SINR). DAS inherit QoS characteristics from the source network—either MNO or shared spectrum model—with overall performance dependent on the system design, signal quality, and backhaul infrastructure.

*5) **Density Handling**:* Wi-Fi primarily relies on legacy OFDM with limited support for OFDMA, and it mitigates co-channel interference through CSMA, which can significantly reduce throughput in high-density environments. MNO or NH networks, in contrast, support dual-domain OFDMA across both time and frequency, offering improved spectral effi-



(a) NH Deployment (b) DAS deployment

Fig. 2: NH & DAS deployment at the healthcare facility.

ciency and more effective interference management. And are specifically engineered for dense user environments, utilizing advanced features such as massive MIMO, and sophisticated interference coordination techniques. DAS has a challenge in high-density scenarios because of same radio resources of MNO (single radio resource across the indoor building), which greatly linmit the max capacity.

6) ***Mobility****:* Wi-Fi relies on client-controlled roaming, where devices perform off-channel scanning and make independent handover decisions, often leading to latency and handoff delays. In contrast, NH and MNO networks implement infrastructure-controlled, precisely timed handovers, following cellular standards to ensure smooth transitions between access points. DAS deliver consistent coverage for mobile users within their deployment areas, provided the system is well-integrated with the underlying MNO to support uninterrupted mobility.

IV. EXPERIMENT ENVIRONMENT AND CONFIGURATION

This section discusses the experiment environment configuration parameters and system utilization for the MNO, Wi-Fi, DAS, and NH systems.

A. MNO Environment, Configuration and System Utilization

In this study, a Google Pixel mobile device equipped with the rooted diagnostic tool *Network Signal Guru (NSG)* was used to monitor detailed cellular band information. Various licensed spectrum bandwidths were observed in the MNO deployment, including 10 MHz, 20 MHz, and 100 MHz allocations. For indoor evaluation, walk tests were conducted at a consistent pace, with paths traversed in both directions to minimize body-shadowing effects from the surveyor. Additional testing was performed using a rolling cart at both low and high speeds within the indoor environment.

The LTE bands detected during measurements included Bands 2, 4, 12, 14, 30, and 66. In the LTE network, the strongest detected Physical Cell Identifiers (PCIs) on Band 2 were 64, 311, and 158. On Band 12, the dominant PCIs were 80, 193, and 250. Weaker signals were noted on Band 14 (PCI 184), Band 30 (PCI 358), and Band 4 (PCI 384). The MNO was found to be operating across both low-band and mid-band spectrum for LTE and NR services. However, no high-band (mmWave) NR operation was detected in the vicinity of the test site. It was consistently observed that signal strength from the MNO network degraded significantly indoors, resulting in poor user experience (as shown in Fig. 4 (a) and (b)), such as difficulty loading applications and establishing voice calls.

B. Wi-Fi Environment, Configurations and System Utilization

In this setup, to analyze the Wi-Fi Radio Frequency (RF) environment, diagnostic tools such as Wi-Fi Explorer Pro and Wireshark were utilized. Consistent with the MNO measurement methodology, walk tests were conducted at a steady pace, with most paths covered in both directions to minimize signal obstruction caused by the surveyor's body. The Wi-Fi cell edge threshold was recorded at a received signal strength of - 88 dBm. Three distinct SSIDs were observed, each supporting dual-band operation. The 2.4 GHz APs were configured with 20 MHz channel widths, using channels 1, 6, and 11. The basic rate was set to 24 Mbps, with the minimum supported rate configured at 12 Mbps. The 5 GHz Wi-Fi APs operated within the UNII-1 and UNII-3 bands, avoiding DFS (Dynamic Frequency Selection) channels. This non-DFS configuration facilitated faster handovers. All 5 GHz APs adhered to the IEEE 802.11ac (Wi-Fi 5) standard and supported both 20 MHz and 40 MHz channel bandwidths.

The client devices used during testing included smartphones from Samsung, Google Pixel, and Apple iPhone. A notable observation was a high beacon overhead, which reduced the effective available bandwidth by up to 12%. Additionally, significant co-channel interference and a high number of active SSIDs contributed to elevated baseline channel utilization. Specifically, the 2.4 GHz band exhibited up to 41% channel utilization even in the absence of associated clients, while the 5 GHz band reached up to 18% utilization with a small number of connected users.

C. NH Environment and Configuration

The NH deployment and corresponding connection setup are illustrated in Fig. 1 and Fig. 2 (a), where its integrated with the private CBRS network infrastructure. Frequency planning was executed using the Celona Self-Organizing Network (SON) algorithm, which autonomously selects optimal EARFCNs and transmit power levels to minimize co-channel interference. The PCI assignment algorithm ensures unique PCI values for each NH AP, thereby eliminating the risk of PCI collisions or confusion.

In addition, a Samsung Galaxy S21+ device was configured with QualiPoc to log detailed data across the PHY, MAC, and application layers. Both walk and cart-based tests were performed, following a custom-designed route intended to replicate realistic user movement within the indoor healthcare facility. This methodology was consistent with the procedures followed in the MNO and Wi-Fi experiments. The collected radio metrics were analyzed using industry-standard post-processing tools. A heatmap visualizing the strong RSRP coverage for the NH deployment is presented in Fig.3 (c).

D. DAS Environment and Configuration

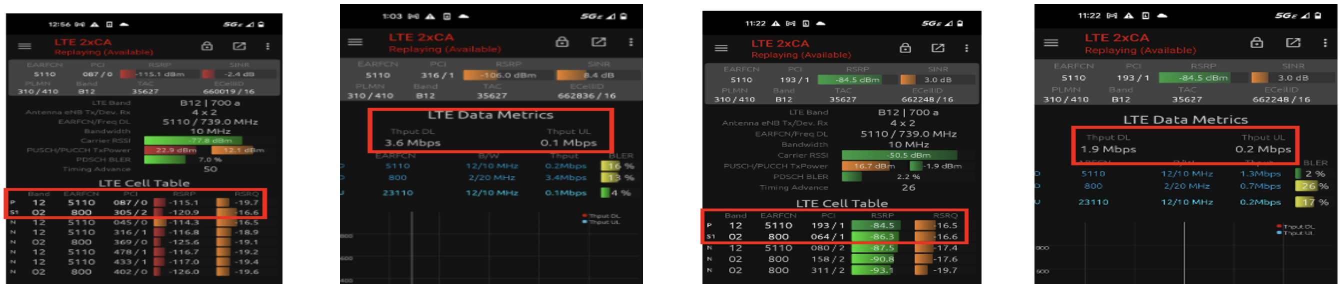
Fig. 2 (b) shows DAS deployment in the indoor ceiling. Its a repeater or signal booster DAS, where the same outdoor

(a) MNO Coverage

(b) DAS Coverage

(c) NH Coverage on Band 48

Fig. 3: *MNO, DAS, and NH RSRP HeatMap*



LTE 2xCA
Replaying (Available)

EARFCN	PCI	RSRP	SINR
5110	087 / 0	-115.1 dBm	-2.4 dB
PLMN	Band	TAC	ECellID
310 / 410	B12	35627	660019 / 16

LTE Band	B12 | 700 a
Antenna eNB Tx/Dev. Rx	4 x 2
EARFCN/Freq DL	5110 / 739.0 MHz
Bandwidth	10 MHz
Carrier RSSI	-77.8 dBm
PUSCH/PUCCH TxPower	22.9 dBm 12.1 dBm
PDSCH BLER	7.0 %
Timing Advance	50

LTE Cell Table

	Band	EARFCN	PCI	RSRP	RSRQ
P	12	5110	087 / 0	-115.1	-19.7
S1	02	800	305 / 2	-120.9	-16.6
N	12	5110	045 / 0	-114.3	-16.5
N	12	5110	316 / 1	-116.8	-18.9
N	02	800	369 / 0	-125.6	-19.1
N	12	5110	478 / 1	-116.7	-19.2
N	12	5110	433 / 1	-117.0	-19.4
N	02	800	402 / 0	-126.0	-19.6

(a) MNO Signal - RSRP

LTE 2xCA
Replaying (Available)

EARFCN	PCI	RSRP	SINR
5110	316 / 1	-106.0 dBm	8.4 dB
PLMN	Band	TAC	ECellID
310 / 410	B12	35627	662836 / 16

LTE Data Metrics

Thput DL	Thput UL
3.6 Mbps	0.1 Mbps

EARFCN	B/W	Thput	BLER
5110	12/10 MHz	0.2Mbps	16 %
800	2/20 MHz	3.4Mbps	13 %
23110	12/10 MHz	0.1Mbps	4 %

(b) MNO Throughput

LTE 2xCA
Replaying (Available)

EARFCN	PCI	RSRP	SINR
5110	193 / 1	-84.5 dBm	3.0 dB
PLMN	Band	TAC	ECellID
310 / 410	B12	35627	662248 / 16

LTE Band	B12 | 700 a
Antenna eNB Tx/Dev. Rx	4 x 2
EARFCN/Freq DL	5110 / 739.0 MHz
Bandwidth	10 MHz
Carrier RSSI	-50.5 dBm
PUSCH/PUCCH TxPower	16.7 dBm -1.9 dBm
PDSCH BLER	2.2 %
Timing Advance	26

LTE Cell Table

	Band	EARFCN	PCI	RSRP	RSRQ
P	12	5110	193 / 1	-84.5	-16.5
S1	02	800	064 / 1	-86.3	-16.6
N	12	5110	080 / 2	-87.5	-17.4
N	02	800	158 / 2	-90.8	-17.6
N	02	800	311 / 2	-93.1	-19.7

(c) DAS Signal - RSRP

LTE 2xCA
Replaying (Available)

EARFCN	PCI	RSRP	SINR
5110	193 / 1	-84.5 dBm	3.0 dB
PLMN	Band	TAC	ECellID
310 / 410	B12	35627	662248 / 16

LTE Data Metrics

Thput DL	Thput UL
1.9 Mbps	0.2 Mbps

EARFCN	B/W	Thput	BLER
5110	12/10 MHz	1.3Mbps	2 %
800	2/20 MHz	0.7Mbps	26 %
23110	12/10 MHz	0.2Mbps	17 %

(d) DAS Throughput

Fig. 4: *Indoor Coverage - MNO and DAS Repeater*

MNO BS signals/channels are used in indoor. The primary used band is Band 2, 20 MHz bandwidth. The PCIs used in indoor are 193 and 64. The duplex mode is FDD. Each floor has multiple deployment of DAS repeator source in the building, but its a single PCI deployed across the building. Hence, its a single radio resource shared across the users in the building. This leads to less per user throughput in downlink and uplink (as shown in Fig. 4 (d)). Also these repeaters can be deployed anywhere in the indoor building, there is no proper co-ordination on minimizing the co-channel or cross-channel interference is performed and this potentially lead to poor SINR. This methodology was consistent with the procedures followed in the MNO/NH and Wi-Fi experiments.

V. EXPERIMENTAL SCENARIOS AND DESCRIPTION

The mobile device is configured with MNO SIM . The tests were run at health-care premises, and the tests were conducted in an indoor environment. This section outlines the different network connectivity scenarios evaluated in the Smart HealthCare environment. Each scenario highlights how the device connects to the respective infrastructure—ranging from outdoor MNO to NH indoor networks.

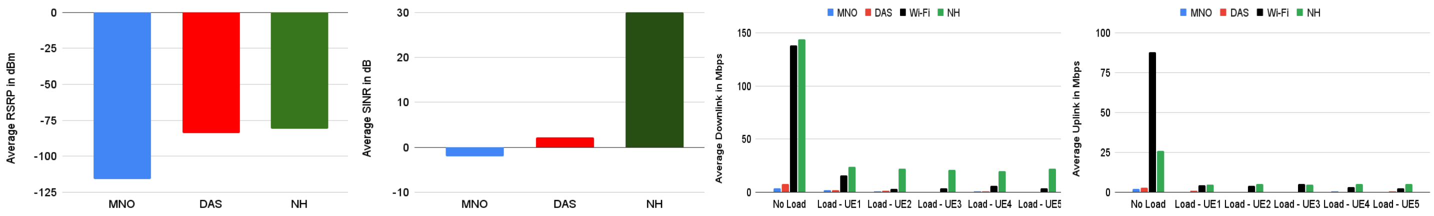
- MNO – There is no indoor DAS operation in this scenario, i.e., DAS is turned OFF. The device connects to only outdoor Macro base station
- DAS – In this scenario, the device connects to the indoor small cell deployed by MNO i.e., DAS is turned ON.
- Wi-Fi – In this scenario, the device connects to the indoor deployed Wi-Fi APs
- NH – In this scenario, the device connects to the NH network deployed by hospital team.

A. Coverage

Fig.3 (a) shows the coverage of only the MNO signal *i.e.,* without an indoor DAS system. We observed more covergae holes in the indoor. The Macro base stations are deployed far from the facility and also the facility is full of e-glass, which eventually observes the electromagnetic signal from the outdoors. Fig.3 (b) shows the coverage of the DAS system, when its turned ON in the indoor environment, we observed the strong RSRP footprint in the indoor environment. Similarly, Fig.3 (c) shows the coverage of NH system, where the indoor region has strong RSRP foot-print throughput the facility compared to the MNO coverage.

B. SINR

The DAS system deployed in this building is a repeater, which broadcast the same channel or frequency of the outdoor base station. Hence, the RSRP signal of the DAS signal will be stronger as shown in Fig. 4 (a) and Fig. 5 (a), because the small cells are deployed inside the building. Bur for the MNO scenario, there is no DAS (no repeator), so the MNO RSRP signal is very low, where the UE cannot connect or make voice call. On the other hand, NH has strong RSRP similar



(a) Average RSRP *(b) Average SINR* *(c) Average Downlink* *(d) Average Uplink*

Fig. 5: *RSRP, SINR, Throughput - MNO, DAS, Wi-Fi and NH*

to the repeator DAS. But strong RSRP doesnt directly relat to high performance, since the DAS, repeats or amplifies the same channel, that leads to poor SINR as shown in Fig. 5 (b), where as the NH has strong SINR, its not repator so it has own channel allocation based on SAS and dynamic SON algrothm allocates the channel effectively, so close-by NH wont interfere each other.

C. Throughput Performance

In this experiment, we used the speed test to record all the throughput performances (as shown in Fig. 5 (c) and (d)). We started our experiment with a single UE to understand the full potential of downlink and uplink performance. Then, in the next step, we added five devices to understand the fairness and load sharing of radio resources among the devices.

In our evaluation of MNO and DAS scenarios, we observed that both systems operated on the same LTE bands (Band 2 and Band 12) and used the same EARFCN for both indoor and outdoor coverage. The overall performance between MNO and DAS appeared to be largely similar. This is likely due to the DAS configuration indoors, where a single access point with multiple antennas or associated PCIs serves the area. While this setup provides good signal coverage (i.e., high RSRP), it does not necessarily translate to high throughput. The indoor performance is limited by the capacity of the single AP, which must share resources across connected devices.

In contrast, Wi-Fi—especially in a single-user environment—demonstrated significantly higher throughput on both the downlink and uplink when configured with a 40 MHz channel width. However, as more devices were added to the Wi-Fi network (e.g., increasing from one to five user devices), performance degraded. This is due to Wi-Fi's contention-based channel access (CSMA/CA), which lacks centralized scheduling. As a result, there is no guarantee of fair bandwidth distribution among devices, leading to uneven throughput and degraded user experience under load. On the other hand, cellular technologies such as MNO, DAS, and CBRS operate with centralized, scheduled access mechanisms based on TDD MAC scheduling. These systems are designed to allocate resources dynamically and fairly, even as the number of connected devices increases. This ensures more consistent throughput and predictable performance in multi-user scenarios compared to the contention-based access of Wi-Fi. Thus, while Wi-Fi may excel in light-load conditions, cellular systems offer more scalable and equitable performance under heavier load.

VI. CONCLUSION

In this paper, we have examined and compared four primary indoor connectivity solutions: MNO, Wi-Fi, CBRS, and DAS. Each technology presents unique strengths and weaknesses, particularly in high-density environments. While Wi-Fi advancements offer increased throughput, they are hindered by unlicensed spectrum contention and channel planning issues. MNO signals, especially mid- and high-band 5G frequencies, face challenges in penetrating building materials, leading to coverage holes. DAS provides enhanced indoor coverage but at a high deployment cost. NH offers robust and reliable connectivity but requires careful spectrum management. Our findings highlight the trade-offs associated with each technology and provide insights into their suitability for various indoor environments.

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