Indoor Sharing in the Mid-Band: A Testbed Evaluation of Neutral-Host, Cellular Macro & Wi-Fi

Joshua Roy Palathinkal*, Muhammad Iqbal Rochman*, Vanlin Sathya†, Mehmet Yavuz†, and Monisha Ghosh*

*Department of Electrical Engineering, University of Notre Dame, †Celona, Inc.

Email: *{jpalathi,mrochman,mghosh3}@nd.edu, †{vanlin,mehmet}@celona.io

Abstract—**Indoor environments present significant challenges for wireless connectivity. Public Mobile Network Operators (MNOs) utilizing outdoor macro base stations (BSs) to serve indoor customers suffer from poor signal penetration while indoor Wi-Fi networks may face reliability issues due to spectrum contention. Shared spectrum models, particularly the Citizens Broadband Radio Service (CBRS) band utilized by private 4G/5G networks, have emerged as a promising alternative to providing reliable indoor service. Moreover, these private networks are equipped with the neutral-host (NH) model, seamlessly offloading indoor MNOs' traffic to the private CBRS network. This paper presents a comprehensive, real-world performance evaluation of three co-located technologies utilizing mid-band spectrum (1–6 GHz): a CBRS-based NH network, public MNO macro networks, and a Wi-Fi 6 network, inside a large, big-box retail store characterized by significant building loss. While the evaluation is site-specific, it is a real-world representation of a highly dense class of indoor deployments. Our analysis demonstrates: (i) the NH network provides superior indoor coverage compared to MNO macro, requiring only six CBRS devices (CBSDs) versus 65 Access Points (APs) for enterprise Wi-Fi to achieve full coverage, with a median building loss of 26.6 dB ensuring interference-free coexistence with outdoor federal incumbents; (ii) the NH network achieves substantial indoor throughput gains, with per-channel normalized throughput improvements of $1.44\times$ and $1.62\times$ in downlink (DL), and $4.33\times$ and $13\times$ in uplink (UL), compared to 4G and 5G macro deployments, respectively; (iii) the NH deployment achieves a median indoor aggregated physical (PHY)-layer DL throughput gain of $2.08\times$ over 5G macro deployments indoors, despite utilizing only 40 MHz of aggregated bandwidth compared to 225 MHz for 5G macro; and (iv) the NH deployment also outperforms Wi-Fi in application-layer HTTP DL performance by $5.05\times$. The findings offer critical insights by presenting: (i) a framework to leverage real-world deployments as testbeds for studying indoor shared-spectrum networks; and (ii) measurement-based evidence supporting the use of NH to improve indoor cellular coverage.**

I. INTRODUCTION

The U.S. Federal Communications Commission (FCC) has spearheaded efforts to meet escalating data demands by significantly expanding access to mid-band (1–6 GHz) frequencies. This initiative includes the auction of several key bands for 5G services: the 2.5–2.69 GHz Broadband Radio Service, the 3.7–3.98 GHz C-band, and the 3.45–3.55 GHz Department of Defense (DoD) band. However, indoor data demands present unique challenges: up to 80% of U.S. mobile data originates or terminates indoors [1], with over 80% offloaded to Wi-Fi [2]. Despite Wi-Fi's expansion into 6 GHz, achieving reliable indoor wireless coverage remains challenging due to Wi-Fi's

lower power and contention-based Medium Access Control (MAC) layer. While the 4G/5G scheduled MAC is more robust, indoor coverage from outdoor macro deployments is similarly challenged due to building penetration losses. Indoor solutions such as Distributed Antenna Systems (DAS) for cellular tend to be very expensive and are not scalable.

To that end, a spectrum sharing model with outdoor incumbents offers an indoor coverage solution, leveraging building loss to separate indoor and outdoor emissions. For instance, the Low Power Indoor (LPI) mode of operation in 6 GHz has shown low probability of harmful interference to outdoor fixed-link incumbents [3, 4], while the 3.55–3.7 GHz Citizens Broadband Radio Service (CBRS) offers low power indoor operations to enable coexistence with outdoor incumbents like Navy radar [5]. More recently, the neutral-host (NH) model deployed by private 4G/5G operators in the CBRS band enables seamless offloading of outdoor Mobile Network Operator (MNO) traffic (data and call) to the private indoor radios to enhance connectivity and performance. While prior work has compared NH to MNO macro [6, 7] and Wi-Fi [8], these studies often lack a deep analysis of the underlying performance gains. Our recent study [9] analyzed the 4G/5G parameters to explain NH performance, but lacked in a direct Wi-Fi comparison. This work bridges that gap by presenting a three-way testbed-based comparative analysis of Wi-Fi, MNO macro, and NH performance—all utilizing the mid-band spectrum—within a large big-box store environment, with results released as a reproducible dataset [10]. This study contributes by presenting a framework to leverage a real-world deployment as a testbed for future mid-band spectrum sharing allocation studies, such as the 3.1–3.45 GHz and 7.125–8.4 GHz bands currently being studied by the National Telecommunications and Information Administration (NTIA) for shared use [11]. Our contributions are as follows:

• **Comparison of coverage between NH, MNO macro, and Wi-Fi (§IV-A, §IV-C):** The NH network achieved better indoor coverage than the MNO macro deployment, requiring only six CBRS devices (CBSDs)—compared to the 65 access points (APs) required to achieve Wi-Fi coverage. Furthermore, a high median building loss of 26.6 dB ensures fair coexistence between the NH network and outdoor incumbents.

• **Comparison of per-channel throughput performance between representative NH and MNO macro (§IV-B):** The NH network achieves median indoor normalized throughput
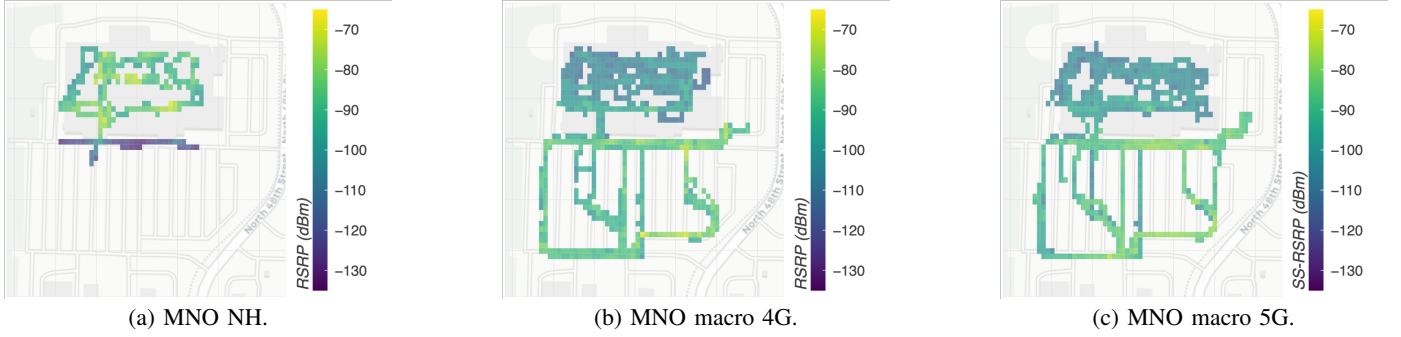
Fig. 1: RSRP heatmap comparison across NH and MNO macro deployments.

TABLE I: Summary of captured network performance parameters.

Parameter	Description
Qualipoc & SigCap: General parameters	
Latitude, Longitude	UE's geographic coordinates
Qualipoc: Radio report parameters	
PCI	Physical Cell Identifier
DL/UL ARFCN	Absolute Radio Frequency Channel Number, *i.e.,* center frequency.
Bandwidth	Range of frequencies available for transmission [MHz]
RSRP/RSRQ	Reference Signal Received Power and Reference Signal Received Quality values. For 5G, RSRP/RSRQ indicates measurements from the 5G Synchronization Signal (SS) block [dBm/dB]
SCS	Subcarrier Spacing numerology; fixed at 15 kHz in 4G
Qualipoc: Throughput & power metrics	
PDSCH/PUSCH Tput.	Throughput at Physical Downlink Shared Channel and Physical Uplink Shared Channel, *i.e.,* physical-layer throughput in downlink and uplink directions [Mbps]
Normalized PDSCH/PUSCH throughput	A calculated metric which normalize physical layer throughput over the number of allocated resource blocks, subcarrier spacing, and MIMO layers [bit/s/Hz/stream] [12]
App. DL/UL Tput.	Application layer throughput in downlink and uplink directions [Mbps]
PUSCH TX power	Uplink TX power used by the UE [dBm]
SigCap: Wi-Fi parameters	
BSSID	Wi-Fi Basic Service Set Identifier that indicates unique identification of a Wi-Fi AP.
Primary channel number	A number associated with a unique BSSID that identifies the frequency of the 20 MHz primary channel [MHz].
RSSI	Received Signal Strength Indicator calculated from a 20 MHz beacon signal [dBm].
TX power	Conducted power of the BSSID [dBm].

gains of $1.44\times$ and $1.62\times$ in downlink (DL) and $13\times$ in uplink (UL) compared to 4G and 5G macro deployments indoors, respectively. Moreover, our user equipment (UE) utilized lower uplink transmit (TX) power when utilizing neutral-host compared to MNO macro.

• **Comparison of user-experienced throughput performance between representative NH, MNO macro, and Wi-Fi (§IV-D):** The NH network achieves a median indoor aggregated PHY-layer DL throughput gain of $2.08\times$ over 5G macro deployments indoors, despite utilizing only 40 MHz of aggregated bandwidth compared to 225 MHz for 5G macro. Additionally, the NH deployment outperforms Wi-Fi in HTTP (Hypertext Transfer Protocol) DL throughput, achieving a $5.05\times$ improvement.

II. METHODOLOGY AND TOOLS USED

Our measurement campaign was conducted in a typical big-box retail store located in a suburban setting. The building is characterized by thick concrete walls (possibly 6–15 inches), glass entrances, and minimal windows. Within this store, users can be served by indoor neutral-host and Wi-Fi networks, or by outdoor-deployed cellular macro BSs. We utilized a Samsung S22+ smartphone capable of connecting to all relevant Wi-Fi and cellular bands, and employed two measurement tools, QualiPoc and SigCap, for comparative network evaluations. The QualiPoc tool actively measure application-layer throughput by looping through a defined test sequence: a 5-seconds HTTP download from *github.com* and a 5-seconds HTTP upload to *httpbin.org*. Concurrently, cellular and Wi-Fi data were passively collected by QualiPoc and SigCap, respectively. QualiPoc collects detailed 4G & 5G PHY-layer data by probing the modem chipset via the *Qualcomm Diagnostic Mode* interface. Conversely, SigCap collects cellular and Wi-Fi data but it is limited to the information exposed by the Android API [13]. Thus, we utilized SigCap exclusively for Wi-Fi analysis. Table I details QualiPoc and SigCap parameters used in our analysis.

The measurements were conducted by walking indoors and outdoors around the retail store, between Feb. 24 to Feb. 26, 2025, capturing $17,400$ m^2 ($187,292$ ft^2) of a large big-box retail store indoors and the adjacent $28,400$ m^2 ($305,695$ ft^2) parking lot outdoors. This store is served by three cellular MNOs labeled MNO-A, MNO-B, and MNO-C. However, only MNO-A & B offload their network to the neutral-host. Fig. 1 shows the coverage footprint of our measurements as heatmaps of captured RSRP from MNO NH and MNO macros. We collected a total of 221,396 datapoints across QualiPoc radio reports, PDSCH (downlink) throughput, PUSCH (uplink) throughput, and application-layer (HTTP session) reports, as well as 570,803 Wi-Fi beacon datapoints from SigCap.

III. DEPLOYMENT OVERVIEW

Neutral-Host & MNO Macro: Table II provides a summary of the 4G and 5G bands observed during the measurement campaign, where 4G bands are denoted with the prefix *'b'* and 5G bands with the prefix *'n'*. Among these deployments, MNO-A & B offloads their indoor users to the neutral-host services in the CBRS b48 band. The NH deployment within the retail store consists of six indoor CBSDs, each configured with two Physical Cell Identifiers (PCIs), resulting in a total of 12 active PCIs. These CBSDs are deployed on ceilings (approximately 4–5 m above ground level) and employ omnidirectional antennas with a TX power and antenna gain of

TABLE II: 4G and 5G bands information.

Operator-Band	Duplex Mode	DL Band Freq. (MHz)	SCS (kHz)	BW (MHz)	#unique PCIs
NH band					
MNO-A b48 MNO-B b48	TDD	3500	15	20	12
MNO macro bands					
MNO-A b2	FDD	1900	15	10, 15	5
MNO-A b12	FDD	700	15	10	5
MNO-A b14	FDD	700	15	10	4
MNO-A b30	FDD	2300	15	10	4
MNO-A b66	FDD	1700	15	10	4
MNO-B b2	FDD	1900	15	5	3
MNO-B b12	FDD	700	15	5	2
MNO-B b66	FDD	1700	15	20	3
MNO-C b2	FDD	1900	15	10	3
MNO-C b5	FDD	850	15	10	2
MNO-C b13	FDD	700	15	10	4
MNO-C b66	FDD	1700	15	10, 20	4
MNO-B n25	FDD	1900	15	10, 15	13
MNO-B n41	TDD	2500	30	90, 100	34
MNO-B n71	FDD	600	15	20	21
MNO-C n77	TDD	3700	30	100	6

TABLE III: Deployment parameters.

Parameters	Values
Neutral-host deployment	
# of deployed CBSD	6 CBSDs
# of PCI	2 per CBSD
Nature of Antenna	Omnidirectional
4G TDD Config	Config #1: DL/UL (# subframes): 4/4
CBSD TX Power	24 dBm
Antenna Gain	3 dBi
Band Number & Channel Frequency	b48: {3560, 3590, 3620, 3650, 3690} MHz
Bandwidth	20 MHz
Channel aggregation	up to 2 channels (40 MHz)
Enterprise Wi-Fi deployment	
	2.4 GHz	5 GHz
# unique BSSIDs	12	65
Wi-Fi TX power	14 dBm	10–19 dBm
Bandwidth	20 MHz	
Wi-Fi standard	Wi-Fi 6 (IEEE 802.11ax)	

24 dBm and 3 dBi to uniformly distribute coverage within the indoor environment. The deployment utilizes five unique 20 MHz channels within the b48 band, enabling channel reuse and segmentation across spatial zones, and also supports aggregation of up to two channels (totaling 40 MHz) for higher capacity. More details on the NH deployment are provided in Table III.

In the cellular macro deployment, all three MNOs have deployed 4G across both low-band (<1 GHz) and mid-band (1–6 GHz) frequencies. 5G deployments were observed for both MNO-B and MNO-C, with higher capacity observed in its mid-band deployments (MNO-B's n41 and MNO-C's n77) as shown by their higher sub-carrier spacing (SCS) and wider bandwidth. Notably, MNO-B demonstrates a dense and diverse 5G deployment with high number of unique PCI across low- and mid-band frequencies.

Enterprise Wi-Fi: To focus our analysis on the retail store's enterprise Wi-Fi network, we filtered beacon data for its specific Service Set Identifier (SSID). Our measurements identified 65 unique 5 GHz and 12 unique 2.4 GHz Basic Service Set Identifiers (BSSIDs), indicating a dense 5 GHz deployment designed for comprehensive indoor coverage. These APs are deployed at on ceilings at the same heights as the CBSDs. They operate with a fixed 20 MHz channel width, suggesting the higher bandwidth allowed in IEEE 802.11ax (40–160 MHz) were likely not configured, potentially to
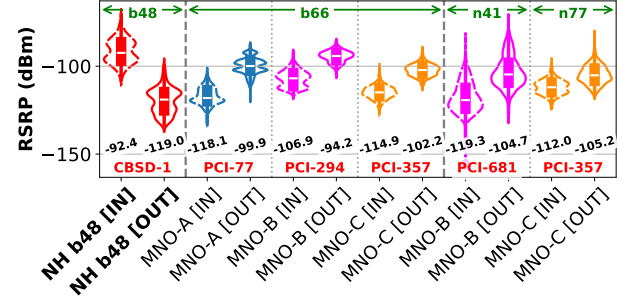

Fig. 2: Coverage statistics for representative CBSD/PCI.

avoid co-channel interference or to prioritize interoperability with legacy clients. Beacon TX power data further reveals that the 2.4 GHz radios operate at a fixed TX power of 14 dBm, and a range from 10 dBm to 19 dBm for the 5 GHz radios, indicative of adaptive power control likely employed to optimize coverage and mitigate co-channel interference.
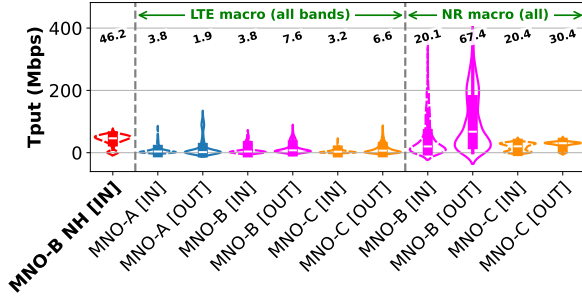
IV. MEASUREMENT RESULTS AND ANALYSES

A. Coverage Comparison of NH and MNO macro

For an overall comparison of coverage between the neutral-host and MNO macro deployments, we refer to the RSRP heatmaps in Fig. 1. Specifically, Fig. 1a illustrates the RSRP heatmap from the CBRS band (b48) utilized by the NH deployment under both MNO-A & B. Each square of the heatmap represents the maximum RSRP over all datapoints within the 6×6 m^2 bin. Figs. 1b and 1c summarizes the coverage of all MNO macros, by combining maximum RSRP captured on all 4G and 5G channels, respectively. We observe higher indoor RSRP from neutral-host compared to macro deployments, and vice versa for outdoor RSRP—an expected outcome given the indoor deployment of neutral-host and the outdoor deployment of MNO macro.
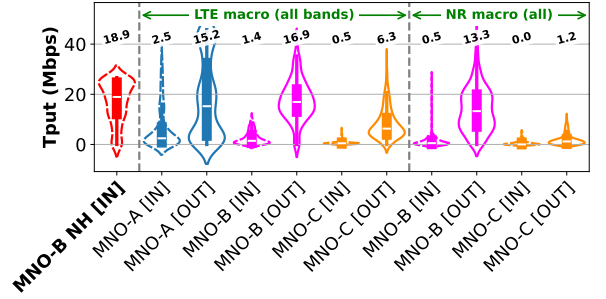
Fig. 2 further illustrates the RSRP distributions for representative PCIs from the NH and MNO macro deployments, grouped by band. These representative PCIs were selected based on having the highest number of measurement points, serving as a proxy for primary coverage cells within the region of analysis. The representative CBSD ("CBSD-1") exhibits a significant building loss with a median indoor-to-outdoor RSRP difference of 26.6 dB. Further, the median RSRP values of the representative MNO macro deployments are high outdoors but degrades substantially indoors. This underscore the limited indoor coverage of outdoor macro deployments even with a potentially high TX power. In contrast, CBSD-1 achieves a notably higher median indoor RSRP of -92.4 dBm while operating at a modest TX power of 24 dBm. This highlights the NH deployment's ability to ensure strong indoor coverage while avoiding outdoor interference.

B. PHY-layer Performance Comparison of NH and MNO macro

Because NH traffic routed to MNO core networks is often treated as "roaming", users may face operator-specific throt-
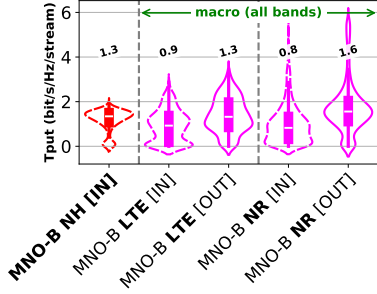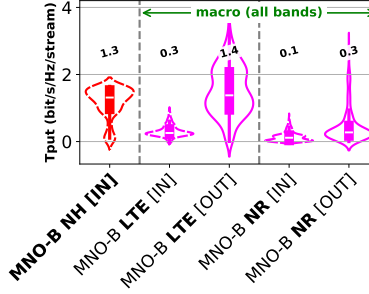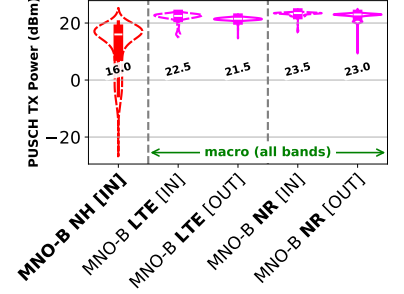
(a) PDSCH throughput.

(b) PUSCH throughput.

Fig. 3: PHY-layer throughput comparison across NH and MNO macro deployments.

(a) Normalized PDSCH throughput.

(b) Normalized PUSCH throughput.

(c) PUSCH TX power distribution.

Fig. 4: PHY-layer performance analysis of MNO-B's NH and macro deployments.

tling. This was confirmed by the NH infrastructure provider and is evident in our data, with a MNO-B-subscribed device achieving 21 Mbps higher median PDSCH throughput indoors than an MNO-A-subscribed one. To ensure a fair and representative evaluation of the NH deployment's capabilities, we therefore focus exclusively on the performance analysis of MNO-B's NH deployment throughout this study.

For a comprehensive view of the MNO macro deployments, Fig. 3 shows the per-channel PHY-layer throughput results for all MNOs and bands, with Figs. 3a and 3b showing the PHY-layer DL and UL performance, respectively. Rather than focusing on representative PCIs—which may introduce site-specific biases—we present an overall comparison by grouping the measurements according to radio access technology (4G LTE or 5G NR) and location type (indoor/outdoor). Given MNO-C 's low indoor DL and UL performance and its lack of traffic offload to the NH infrastructure, it is clear that MNO-C could benefit from the superior performance provided by neutral-hosts. In particular, MNO-B 's macro 5G network delivers superior outdoor performance in the downlink direction. For UL throughput, the NH network's indoor performance is comparable to the outdoor performance of MNO-A in 4G as well as MNO-B in 4G and 5G. Since our NH analysis uses data from the representative MNO-B network, we focus exclusively on MNO-B 's NH and macro deployments for the rest of our evaluation to maintain consistency and fairness.

To enable a deeper analysis of radio link performance under fixed resource conditions, we normalize the PHY-layer throughput over the number of allocated resource blocks,

subcarrier spacing, and MIMO layers: effectively capturing the channel spectral efficiency per spatial stream. We employ this metric—expressed in bit/s/Hz/stream—for comparison purposes, with its detailed formulation available in [12]. The resulting distribution of normalized PDSCH and PUSCH throughput are shown in Figs. 4a and 4b, respectively. Looking at the normalized DL results in Fig. 4a, our MNO-B-subscribed indoor user achieves a median throughput of 1.3 bit/s/Hz/stream when served by the NH network, which represents gains of $1.44\times$ and $1.62\times$ over MNO-B's own 4G and 5G macro deployments, respectively. Fig. 4b shows a median normalized UL throughput of 1.3 bit/s/Hz/stream for neutral-host, which is similar to its DL counterpart and consistent with its balanced 4G TDD configuration (4 subframes each for DL and UL). Notably, indoor UL performance gain over 4G and 5G macro deployments is even higher than that observed in the DL, with median gains of $4.33\times$ for 4G and $13\times$ for 5G. These results underscores the effectiveness of the indoor NH system, which—despite consisting of only six low-power CBSDs—matches the spectral efficiency of resource-intensive outdoor macro deployments. Notably, the NH deployment achieves comparable normalized DL performance while relying on a significantly smaller infrastructure footprint and lower TX power.

To complement the PHY-layer performance analysis, Fig. 4c reveals that PUSCH TX power required by the UE is significantly lower when utilizing the NH network. In contrast, macro networks exhibits higher UE TX power usage, suggesting a potential advantage of neutral-host model in terms

(a) Wi-Fi 2.4 GHz RSSI map   (b) Wi-Fi 5 GHz RSSI map   (c) Connected Wi-Fi band usage.
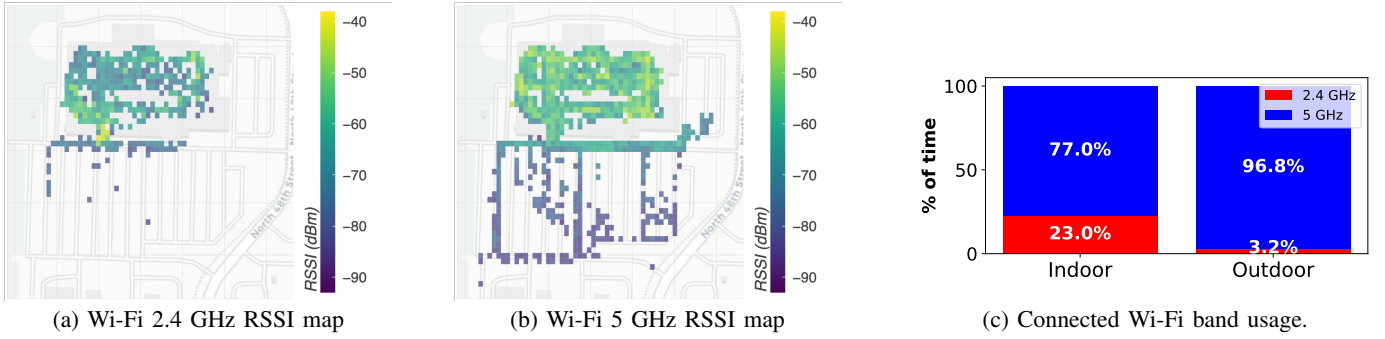
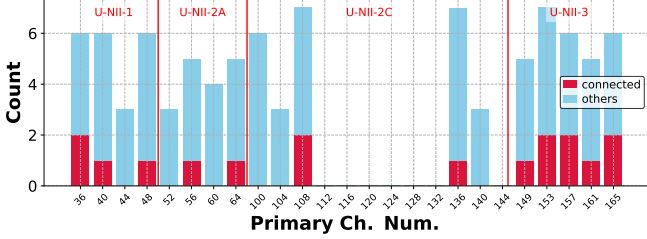Fig. 5: Wi-Fi coverage maps and time-based band usage statistics.

Fig. 6: Number of unique BSSIDs across 5 GHz channels

of UE's energy efficiency.

While the QualiPoc tool is capable of capturing a wide range of PHY-layer parameters, we omit detailed analyses here, as a comprehensive PHY-layer study of the NH deployment has already been presented in our prior work [9] and is not repeated here. These findings collectively suggest that NH deployments offer not only competitive DL/UL performance but also reduced UE power demands, contributing to a more energy-efficient user-experience.

C. Coverage Analysis of Enterprise Wi-Fi

We assess the enterprise Wi-Fi coverage quality by analyzing the RSSI heatmaps in Figs. 5a and 5b. Additionally, Fig. 5c presents the percentage of time UE was connected to the 2.4 GHz and 5 GHz bands, both indoors and outdoors. These results show that the 5 GHz band has more coverage (consistent with its higher AP deployment density), and that the UE prefers the 5 GHz band 77% of the time indoors. Based on this, we use the 5 GHz band as the representative Wi-Fi band in all future analyses to ensure a fair comparison.

To further understand 5 GHz Wi-Fi spectrum utilization, Fig. 6 presents the number of unique BSSIDs both scanned and connected to across the available 5 GHz channels. The distribution is generally uniform across most channels, indicating a balanced channel assignment. However, channels within the U-NII-2C sub-band are notably underutilized, with several channels not being used at all. This may be attributed to dynamic frequency selection (DFS) restrictions: U-NII-1 and U-NII-3 bands might be more preferable to maintain inter-operability with Wi-Fi clients that does not support DFS. The extensive 5 GHz coverage—achieved with 65 APs—contrasts sharply with the six CBSDs utilized by the NH network,

highlighting the NH deployment's efficiency in delivering robust indoor coverage with significantly fewer infrastructure resources.

D. User-Experience Throughput Comparison Between NH, MNO macro, and Wi-Fi

While §IV-B provided a per-channel PHY-layer throughput analysis, it is more relevant from a user-experience perspective to consider the aggregated throughput across all connected bands, as shown in Fig. 7a. MNO-B 's 5G macro network (operating in 5G standalone mode) achieves a substantially higher median aggregated PDSCH throughput, benefiting from the aggregation of up to four 5G channels (totaling 225 MHz). In comparison, the NH deployment aggregates only two 4G channels (20 MHz each, for a total of 40 MHz), while MNO-B 's 4G macro uses up to three 4G channels (totaling 30 MHz). Interestingly, despite the higher bandwidth available to the MNO-B macro 5G, the indoor performance of neutral-host outperforms the 5G macro $2.08\times$ times. This indicates that, even though NH operates on 4G with limited bandwidth, its indoor-based deployment yields superior performance compared to outdoor-deployed 5G—demonstrating that deployment location can be just as crucial as spectrum resources in determining system performance.

To incorporate Wi-Fi into the end-user performance evaluation, we compare DL and UL application-layer throughput across neutral-host, MNO macro, and enterprise Wi-Fi deployments. The throughput was measured using controlled HTTP GET and PUT requests, corresponding to DL and UL traffic, respectively. For each session, application-layer throughput was calculated by dividing the total amount of data transferred by the session duration. Thus, the measured HTTP-layer throughput represents aggregate performance across active radio channels, encompassing scenarios such as 4G-only (aggregating solely 4G channels), 5G Standalone (solely 5G channels), or 5G Non-Standalone (combinations of 4G and 5G channels). Conversely, the application-layer throughput under Wi-Fi networks remains constrained to the 20 MHz channel used. The results are summarized in Figs. 7b and 7c, which respectively show the distribution of DL and UL application-layer throughput across technologies and environment.

Fig. 7b shows the indoor DL performance of MNO-B's NH outperforms enterprise Wi-Fi with a $5.05\times$ improvement.

(a) Aggregated PDSCH throughput.

(b) HTTP DL throughput.
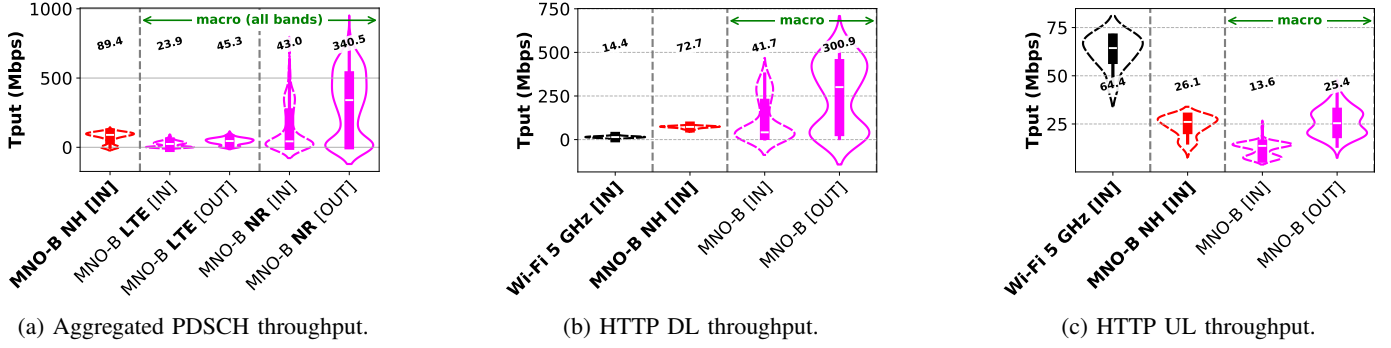
(c) HTTP UL throughput.

Fig. 7: User-experienced throughput statistics.

Further comparisons with MNO-B's macro deployments corroborate the aggregated PHY-layer PDSCH throughput results presented in Fig. 7a. In the UL, Fig. 7c shows that Wi-Fi achieves a notably high median UL throughput of 64.4 Mbps indoors—surpassing its own DL performance. This asymmetry is likely due to the different target hosts used for the HTTP GET (download from *github.com*) and PUT (upload to *httpbin.org*) requests, which may impose varying routing paths, congestion handling, or server-side rate controls that affect measured throughput [14]. Excluding Wi-Fi, the NH network again shows strong UL performance comparable to outdoor macro performance and exceeding indoor macro performance by $1.92\times$.

Taken together, these results demonstrate that the NH network provides competitive user-experience performance when compared to indoor Wi-Fi and indoor MNO macro deployments, while also remaining competitive with macro-cellular performance in outdoor scenarios—when evaluated critically for bandwidth resource utilization. Our evaluation considered both aggregated PHY-layer PDSCH throughput and application-layer HTTP throughput as metrics for assessing user-experienced performance, ensuring a comprehensive view of network effectiveness.

V. CONCLUSIONS AND FUTURE WORK

This study presents a comprehensive in-situ evaluation of mid-band deployments—enterprise Wi-Fi, MNO macro, and neutral-host networks—at a large big-box store, focusing on coverage, PHY-layer and application-layer throughput. Our measurements reveal that while Wi-Fi requires 65 APs to achieve extensive indoor coverage, the NH deployment provides comparable coverage with just six CBSDs and offers superior indoor coverage compared to MNO macro deployments. Analyzing PHY-layer performance, the NH network consistently outperforms the MNO macro indoors in both downlink and uplink, for both per-channel and aggregated throughput. Application-layer HTTP downlink throughput analysis further reinforces that the NH network provides a superior user experience compared to Wi-Fi and indoor MNO macro deployments, making it a strong candidate for future mid-band indoor connectivity solutions.

REFERENCES

[1] Ericsson, "Ericsson Mobility Report, November 2023," Retrieved from https://www.ericsson.com/en/reports-and-papers/mobility-report/reports.

[2] M. Calabrese and J. Dine, "The next frontier in spectrum policy: Indoor-only sharing of federal bands," Retrieved from https://www.newamerica.org/oti/reports/the-next-frontier-in-spectrum-policy/, Nov. 2024.

[3] S. Dogan-Tusha, M. I. Rochman, A. Tusha, H. Nasiri, J. Helzerman, and M. Ghosh, "Evaluating the interference potential in 6 GHz: An extensive measurement campaign of a dense indoor Wi-Fi 6E network," in *Proceedings of the 17th ACM Workshop on Wireless Network Testbeds, Experimental evaluation & Characterization*, 2023, pp. 56–63.

[4] S. Dogan-Tusha, A. Tusha, H. Nasiri, M. I. Rochman, and M. Ghosh, "Indoor and outdoor measurement campaign for unlicensed 6 GHz operation with Wi-Fi 6E," in *2023 26th International Symposium on Wireless Personal Multimedia Communications (WPMC)*. IEEE, 2023, pp. 1–6.

[5] A. Tusha, S. Dogan-Tusha, J. R. Palathinkal, H. Nasiri, M. I. Rochman, P. McGuire, and M. Ghosh, "A comprehensive analysis of secondary coexistence in a real-world CBRS deployment," *IEEE Transactions on Cognitive Communications and Networking*, 2025.

[6] R. Bajracharya, R. Shrestha, H. Jung, and H. Shin, "Neutral host technology: The future of mobile network operators," *IEEE Access*, vol. 10, pp. 99 221–99 234, 2022.

[7] V. Sathya, M. Shah, and M. Yavuz, "Neutral host deployment-a measurement study on routing and mobility management between public and private network," in *2023 IEEE Future Networks World Forum (FNWF)*. IEEE, 2023, pp. 1–8.

[8] V. Sathya, L. Zhang, M. Goyal, and M. Yavuz, "Warehouse deployment: A comparative measurement study of commercial Wi-Fi and CBRS systems," in *2023 International Conference on Computing, Networking and Communications (ICNC)*. IEEE, 2023, pp. 242–248.

[9] M. I. Rochman, J. R. Palathinkal, V. Sathya, M. Yavuz, and M. Ghosh, "Neutral-hosts in the shared mid-bands: Addressing indoor cellular performance," 2025. [Online]. Available: https://arxiv.org/abs/2505.18360

[10] Dataset, https://github.com/joshuaroy873/2025-IEEE-CCNC-MNO_NH_WIFI6.

[11] National Telecommunications and Information Administration, "The National Spectrum Strategy," Retrieved from https://www.ntia.gov/sites/default/files/publications/national_spectrum_strategy_final.pdf, 2023.

[12] M. I. Rochman, W. Ye, Z.-L. Zhang, and M. Ghosh, "A comprehensive real-world evaluation of 5G improvements over 4G in low-and mid-bands," *IEEE Transactions on Cognitive Communications and Networking*, 2025.

[13] V. Sathya, M. I. Rochman, and M. Ghosh, "Measurement-based coexistence studies of LAA & Wi-Fi deployments in chicago," *IEEE Wireless Communications*, vol. 28, no. 1, pp. 136–143, 2020.

[14] Y. He, M. Faloutsos, S. Krishnamurthy, and B. Huffaker, "On routing asymmetry in the internet," in *GLOBECOM'05. IEEE Global Telecommunications Conference, 2005.*, vol. 2. IEEE, 2005, pp. 6–pp.