Spectrum Sharing Characterization Using Smartphones: Exploring 6 GHz Sharing Through Large-Scale Wi-Fi 6E Measurements

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Abstract

Spectrum is increasingly being shared between new entrants and incumbents, for example in the 3.55–3.7 GHz Citizens Broadband Radio Service (CBRS) and the 6 GHz unlicensed band (5.925–7.125 GHz). Sharing in these bands is between a commercial system, such as cellular or Wi-Fi and incumbent services like radars, fixed microwave links or satellite links. It is important to learn from these deployed systems through detailed measurements to evolve existing methodologies for new bands. However, there are no large-scale wireless community testbeds explicitly devoted to evaluating sharing in new bands such as 6 GHz, but commercial deployments are proliferating and can be leveraged for experimental studies using the right approach. Hence, in this article we describe tools and methodologies that can be used to quantify the performance of real-world spectrum sharing, using the 6 GHz band as an example. We present detailed analyses based on extensive measurements on dense deployments at the University of Michigan (UMich) and the University of Notre Dame (UND) that show that the proposed sharing mechanism is working well: measured signal strength outdoors from indoor deployments, ranging from –81 dBm to –89 dBm over 20 MHz, do not pose interference risk. Further, our methodology allows us to determine appropriate enabling signal levels for client-to-client (C2C) communications that protect incumbents. In addition to the tools and methodology developed, the dataset collected in this work will be publicly available for the community for further research in spectrum sharing.

Introduction

There have been a number of community and city-scale testbeds available in recent years, such as the Platforms For Advanced Wireless Research (PAWR) [1], for academics to pursue experimentation at scale in different frequency bands using mostly software-define-radios (SDRs) and some limited commercial systems. However, these cannot fully replicate real-world environments for all new bands. For example, there are no testbeds that are capable of measurements in the 6 GHz band (5.925–7.125 GHz) that has been available for unlicensed, but shared, low-power-indoor (LPI) use since 2020, and recently expanded to outdoor use using standard power (SP) with automated frequency coordination (AFC). Thus, there needs to be an alternate way, especially in the spectrum sharing research area, where existing deployments, instead of custom-built SDR-based testbeds are leveraged for research. In this article, we focus on the 6 GHz band where there are increasing operational deployments, mostly in universities, which can be measured using smartphones to develop an understanding of the potential for interference to incumbents. We present our tools, methodologies and analyses from extensive measurements at the University of Michigan (UMich) and University of Notre Dame (UND) which have provided an unique dataset in the 6 GHz band, which will be made publicly available: we believe that this is the only such detailed data-set in the world and can be used by the community to improve analyses and understanding of spectrum sharing in 6 GHz.

Unlicensed spectrum has been a catalyst for innovation in wireless communications, due to its free and shared nature. The exponential growth in traffic demands, driven by the bandwidth needs of emerging wireless applications, has led to a global push for expanded utilization of the 6 GHz spectrum for unlicensed use. Many developed countries have adopted the 5945–6425 MHz band and are considering extending this to 6425–7125 MHz [2]. In the U.S., the Federal Communications Commission (FCC) opened the entire 6 GHz band (U-NII-5 to U-NII-8, see Fig. 1) for shared use with fixed link incumbents [3]. Wi-Fi 6E has emerged as the dominant technology in the 6 GHz band, with approximately 350 million devices shipped in 2022, and further growth expected with the upcoming deployment of Wi-Fi 7.

Several university campuses have dense deployments of Wi-Fi 6E access points (APs) using the LPI regime, and are beginning to deploy outdoors as well. These deployments can serve as ideal, real-world testbeds to assess how the 6 GHz sharing rules are performing, especially with respect to incumbent protection. To this end, we conducted large-scale measurement campaigns with detailed statistical analyses of interference instead of relying solely on single-point, worst-case analyses. Data obtained from our campaigns can

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offer valuable insights and essential information to help navigate the ongoing discussions on the very-low-power (VLP) and client-to-client (C2C) expansions of the current rules.

This article is organized as follows: we outline the current and proposed FCC rules governing 6 GHz sharing; we describe high-level details of our scalable and reproducible device-based measurement methodology; we present the use of device-based measurement methodology in real-world deployments, highlights the primary findings regarding indoor and outdoor emissions and connectivity of LPI APs and provides an in-depth analysis of C2C connectivity in 6 GHz; we discuss the future research opportunities using the presented methodology and lastly, concluding remarks and potential future directions are provided.

FCC Actions

To fairly coexist with the incumbents in the 6 GHz band, the First Report and Order (R&O) released by the FCC on April 24, 2020 introduced two power regimes for unlicensed operations: SP operates at higher power, constrained by AFC, while LPI uses lower power without AFC but is restricted to indoor use, prohibiting weatherized gear, external antennas, and battery power [3]. SP APs are permitted to operate over U-NII-5 and U-NII-7 with a maximum effective isotropic radiated power (EIRP) of 36 dBm, as given in Table 1. They can be deployed indoors or outdoors under the control of the AFC. LPI APs are limited to a maximum power spectral density (PSD) of 5 dBm/MHz and maximum EIRP of 30 dBm across the 6 GHz band, corresponding to higher maximum EIRP for wider channels, e.g. 18 dBm for 20 MHz, 21 dBm for 40 MHz, 24 dBm for 80 MHz, 27 dBm for 160 MHz and 30 dBm for 320 MHz. This limits the interference to mainly fixed link incumbents which are narrowband, typically 30 MHz wide. Since client devices (STAs) associated with an AP are mobile and potentially could be outdoors, they are mandated to operate at 6 dB lower EIRP than the APs. Following the R&O, the deployment of LPI APs occurred rapidly, and a significant number of LPI devices are currently in use across the U.S. SP operations with AFC have also just begun: UND has 862 SP APs deployed in the stadium.

On September 28, 2023, the FCC released the Second R&O and Further Notice of Proposed Rulemaking (FNPRM) on the unlicensed use of 6 GHz while maintaining the protection of the existing incumbent from potential harmful interference [4]. The Second R&O allows VLP operations in two U-NII bands, U-NII-5 and U-NII-7. VLP devices can operate indoors or outdoors without requiring an AFC system, but they cannot be deployed outdoors as part of fixed infrastructure installations. VLP devices are allowed to operate with maximum 14 dBm EIRP irrespective of occupied bandwidth. The second FNPRM seeks comment for:

- Authorization of VLP devices in U-NII-6 and U-NII-8,
- Geofenced VLP devices with higher power levels,
- Enabling C2C in 6 GHz, allowing direct communication of STAs with each other.

VLP devices support a broad spectrum of mobile devices, incorporating body-worn devices, and virtual/augmented reality technologies, to enhance healthcare, learning and entertainment opportunities. VLP operations on U-NII-5 and U-NII-7 has facilitated the flexible utilization of the 6 GHz bands, and it is expected to roll-out swiftly. Proponents of unlicensed operations in the 6 GHz, such as Wireless Alliance, Apple Inc., Broadcom Inc. Google LLC, Intel Corporation, Meta Platforms, Inc. Microsoft Corporation Qualcomm Inc., have presented several studies demonstrating that VLP operations will not induce harmful interference on the incumbents [5, 6]. On December 13, 2024, the FCC issued the Third R&O, opening the entire 6 GHz band for VLP operations [7]. On the other hand, existing incumbents in U-NII-6 and U-NII-8, such as electronic news-gathering (ENG) services, broadcast auxiliary service (BAS), and satellite services, express their concerns about potential harmful interference that could disrupt their operations.

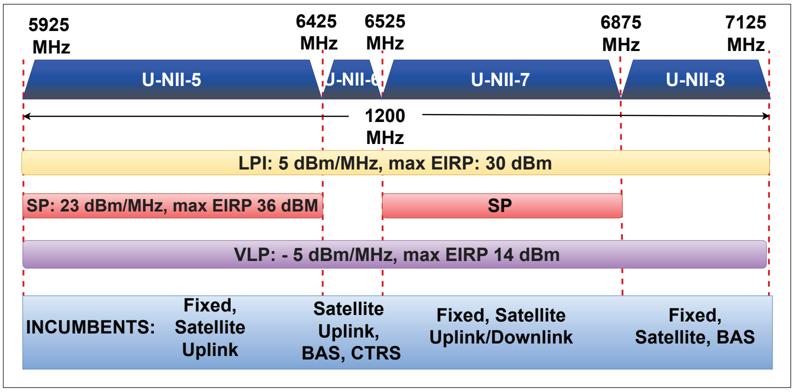

FIGURE 1. Spectrum sharing in 6 GHz band.

The second FNPRM proposes allowing VLP devices to operate at a total power of up to 21 dBm EIRP, regulated by geofencing controls. This approach seeks to protect incumbent services while enabling new high-power VLP applications and use cases. The geofencing system defines exclusion zones for high-power VLP devices around incumbent operation sites, considering factors like VLP device power levels, mobility versus stationary scenarios, and the frequencies used by incumbents.

The first R&O prohibits direct communication between STAs in the 6 GHz band. C2C communications may be enabled when client devices establish a direct communication link with each other, bypassing the indoor AP, based on the received signal strength of an "enabling signal" transmitted by an AP. Such a mode can improve Wi-Fi 6E performance, for example, reducing latency between client devices by avoiding the extra hop in transmissions via the AP. However, the threshold at which the enabling signal should be received is crucial: if set too low, it might enable outdoor clients to communicate with each other at LPI levels thus potentially increasing the probability of interference to incumbents, and if set too high it may preclude indoor clients from communicating with each other and thus reduce the efficacy of this mode. The second FNPRM requests comments to address the following crucial questions:

- The defining the C2C enabling signal and its characteristics,
- Appropriate level of enabling signal,
- Enabling signal refresh interval of four seconds,
- On whether client devices should be limited to receiving an enabling signal from the same

Ensuring an optimal enabling signal level is crucial for establishing a robust C2C communications while maintaining the protection of the incumbents.

Unlicensed Operation	Env.	Band	Max EIRP	Control Mec.	R&O, FNPRM	Status
SP	Indoor	U-NII-5, U-NII-7	AP: 36 dBm, STA: 30 dBm	AFC	1st R&O	Approved
LPI	Indoor/ Outdoor	U-NII-5, U-NII-6, U-NII-7, U-NII-8	AP: 30 dBm, STA: 24 dBm	No	1st R&O	Approved
VLP	Indoor/ Outdoor	U-NII-5, U-NII-7	14 dBm	No	2nd R&O	Approved
VLP	Indoor/ Outdoor	U-NII-6, U-NII-8	14 dBm	No	3rd R&O	Approved
Geofenced VLP	Indoor/ Outdoor	U-NII-5, U-NII-6, U-NII-7, U-NII-8	21 dBm	Geofencing Req.	2nd FNPRM	Proposed
C2C	Indoor	U-NII-5,U-NII-6, U-NII-7, U-NII-8	For LPI Devices	Enabling Signal Level	2nd FNPRM	Proposed

TABLE 1. FCC actions in different bands of 6 GHz.

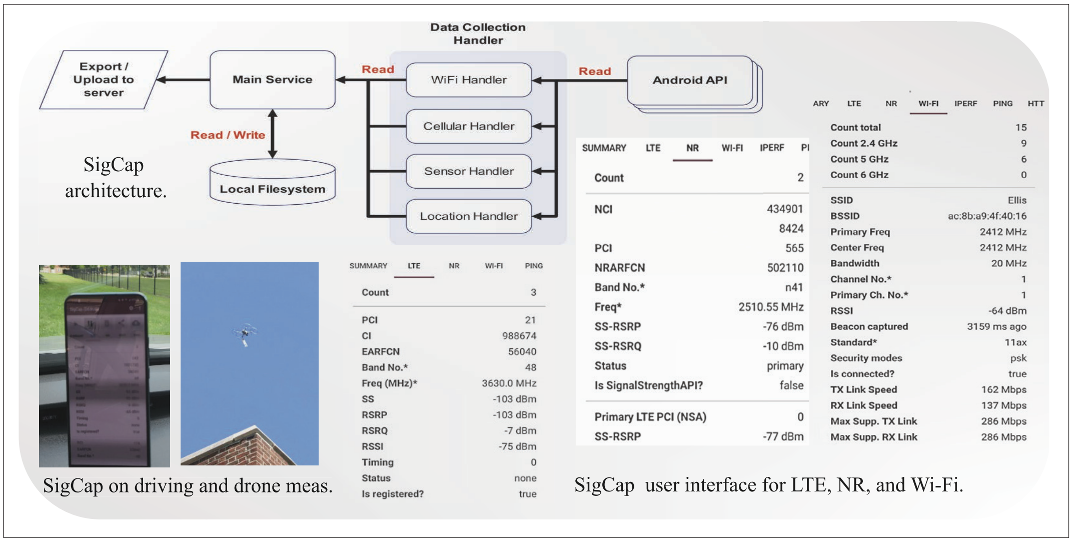

FIGURE 2. SigCap architecture, example methodology, and captured data.

AP or from any authorized APs.

The initial proposal submitted to the FCC evaluates an enabling signal level of –82 dBm/20 MHz, assuming no single-AP limitation [8]. Randomness in the wireless environment can cause variations in the received signal strength indicator (RSSI) of the enabling signal received by a STA, even when the device remains stationary. Consequently, establishing a high RSSI threshold may result in unreliable C2C connectivity. Ensuring an optimal enabling signal level is crucial for establishing a robust C2C communications while maintaining the protection of the incumbents. Hence, it is clear that there are a number of open research problems that need to be addressed. Existing 6 GHz deployments should be leveraged to address these: or aim in this article is to present a methodology, and an initial dataset, that can be used to tackle these problems.

Device-Based Measurement Methodology

We have developed a measurement methodology using smartphones and apps that is scalable due to the low cost and ease of use. Table 2 summarizes the Wi-Fi parameters collected using tools and devices in our campus-wide measurements.

SigCap, our custom Android app, enables passive collection of time- and geo-stamped cellular and Wi-Fi signal data through Android APIs, without requiring root access [9, 10]. Due to the portability, this methodology can be used to capture signal environment while driving or walking, or even using a drone, as shown on the bottom left figures in Fig. 2. The architecture diagram of SigCap given in Fig. 2 shows that data is pooled from the Android API every 5 seconds and handled by the respective data collection handler to be temporary written to local storage and exported/uploaded to a server later. In particular, the Wi-Fi Handler handles the capturing and decoding of Wi-Fi beacon frames from multiple APs to extract the contained information: basic service set identifiers (BSSID), SSID, RSSI, and operating frequency and bandwidth. It's important to note that the RSSI value is measured solely on the Wi-Fi beacon, which operates on a 20 MHz bandwidth. Additionally, some APs broadcast optional beacon elements that the app decodes: transmit signal power, number of stations connected to each BSSID, and channel utilization (percentage of time that the AP senses the primary channel to be busy). Fortunately, all the Wi-Fi 6E APs deployed in UMich and UND broadcast these optional elements, thus facilitating our analysis. In addition to

Wi-Fi parameters, the Cellular Handler also collects cellular parameters from 4G and 5G cells (e.g., physical cell ID (PCI), frequency, reference signal received power (RSRP)) and device sensors data (e.g., battery energy, device and skin temperature). The bottom right figures of Fig. 2 show the snapshot of collected LTE, NR, and Wi-Fi data as shown in the SigCap user interface. The collected data can then be extracted as JSON and CSV files for further analysis, [11] shows example of CSV files describing the overall data, and focused cellular and Wi-Fi data.

Applying the Methodology in Real-World Wi-Fi 6E Deployments

This section showcases the application of our proposed measurement methodology in real-world deployments, demonstrating how to evaluate the collected data effectively. By leveraging the measurement campaigns conducted at UMich and UND using this methodology, we can shed light on the concerns raised regarding the unlicensed use of the 6 GHz band. The analysis focuses on two key areas: outdoor RSSI propagation caused by 6 GHz LPI APs and C2C connectivity.

UMich has deployed what could arguably be the world's largest Wi-Fi 6E network, with over 16,000 APs indoors across numerous university buildings, operating under the 6 GHz LPI regulations. We conducted extensive series of campaigns in the main campus area (MCA) and residential area (RA) through walking, driving, and drone measurements. These measurements took place throughout 2023 to evaluate the impact of dense deployment of Wi-Fi 6E LPI APs on outdoor RSSI measured on 20 MHz beacon frames transmitted by the LPI APs. It is important to note that the MCA has denser deployment of 6 GHz LPI APs than the RA with 227 indoor APs [9].

UND has initiated the upgrade of its Wi-Fi infrastructure, and we have conducted comprehensive measurements indoors and outdoors at the Office of Information Technology (OIT) building with 70 LPI Wi-Fi 6E APs, to evaluate Wi-Fi 6E network performance. While not as extensive as the deployment at UMich, this single building enables us to focus on characterizing the outdoor RSSI footprint of a typical setup of Wi-Fi 6E LPI APs, and offers a controlled environment for focused analysis. It is important to note that the authors' previous work conducted at the UND [12] focuses only on outdoor channel connectivity and building entry loss near a solid brick wall.

Analysis on Outdoor RSSI Propagation and Potential Interference

The primary aim of our measurement campaigns at UMich has been to evaluate the potential interference caused by a densely deployed Wi-Fi 6E network to outdoor fixed link incumbents in 6 GHz band, released for unlicensed use on a shared basis. Figure 3 shows outdoor RSSI heatmaps of UMich MCA and UND based on the collected Sigcap data during walking measurements, ranging from −94 dBm to −50 dBm and from −95 dBm to −65 dBm, respectively. The top figure reveals a clear correlation between the observed outdoor RSSI levels and the density of LPI APs at UMich MCA. Areas with a higher concentration of LPI APs exhibited higher RSSI levels, while regions with fewer LPI APs displayed lower RSSI values. On the bottom figure of Fig. 3, the majority of higher outdoor RSSI levels were observed near glass doors and windows, reaching distances up to 120 m at the main entrance of the OIT building at UND due to the double glass door. We observed that despite having 70 LPI Wi-Fi 6E APs, with 140 BSSIDs, 4 was the median number of unique BSSIDs observed outdoors at UND.

Tool	Wi-Fi Parameters	Devices
SigCap	**Beacon Packet Only:** Time-stamp, GPS Coordinate, BSSID, SSID, Frequency, RSSI, #$STA, TX Power, Channel Utilization	1 × Google Pixel 6, 1 × Samsung S21 Ultra, 3 × Samsung S22+

TABLE 2. Measurement tool, parameters and devices.

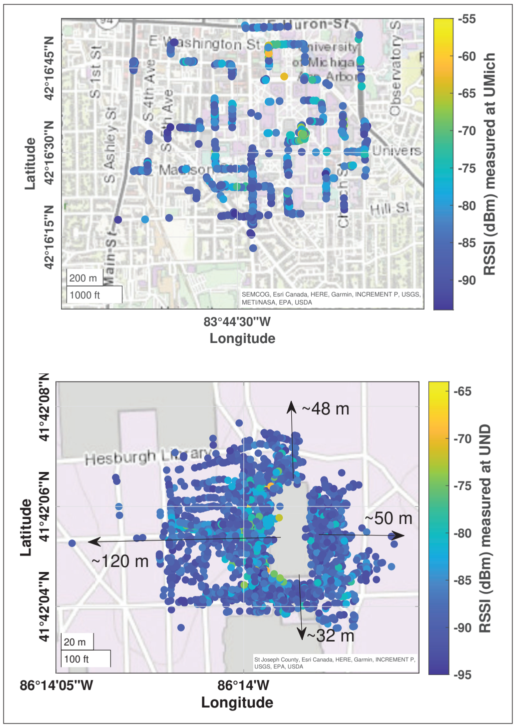

FIGURE 3. RSSI heatmaps for UMich MCA and UND via the collected SigCap data.

The left figure of Fig. 4 shows the CDF of RSSI for outdoor driving and walking measurements at UMich and walking measurements at UND. We observed transmit power levels ranging from 15 dBm to 21 dBm within the MCA, with 95% of the RSSI measurements having a transmit power of 18 dBm or lower, whereas a single transmit power of 21 dBm was measured within the RA. The observed outdoor RSSI levels ranged from −94 dBm to −62 dBm for the MCA driving measurements, and from −92 dBm to −55 dBm for the walking measurements at the MCA and RA. As the majority of the university campus is pedestrian-only access, fewer measurements were taken while driving compared to walking. Driving measurements over the MCA resulted in 3 dB lower median RSSI value than that walking measurements as they were conducted at longer distances from the buildings. Despite LPI APs in the RA operating at higher transmit power levels, the median RSSI value in the MCA was −81 dBm, while in the RA, it was lower at −84 dBm due to sparser deployment compared to the MCA. Moreover, the median RSSI value measured while walking outdoors around OIT

With the rising adoption of Wi-Fi 6E technology, which operates in the 6 GHz frequency band, real-world deployment data becomes increasingly valuable, and can provide much-needed insights to guide the process of determining optimal signal levels for C2C communication in 6 GHz.

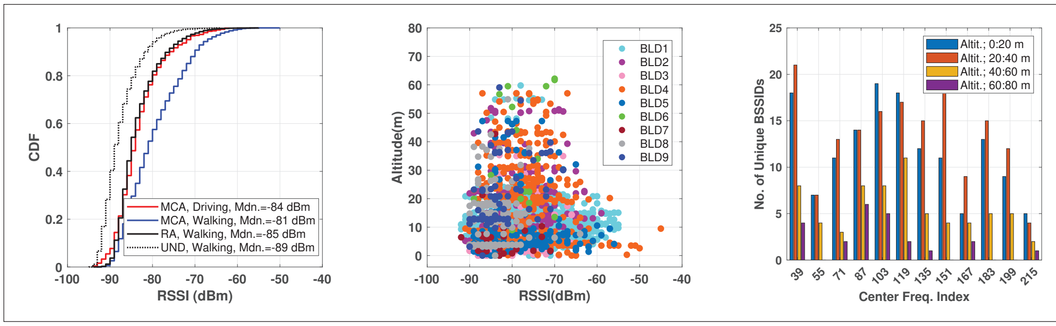

FIGURE 4. Analysis of UMich measurements to understand outdoor RSSI propagation and potential interference to incumbents in 6 GHz band.

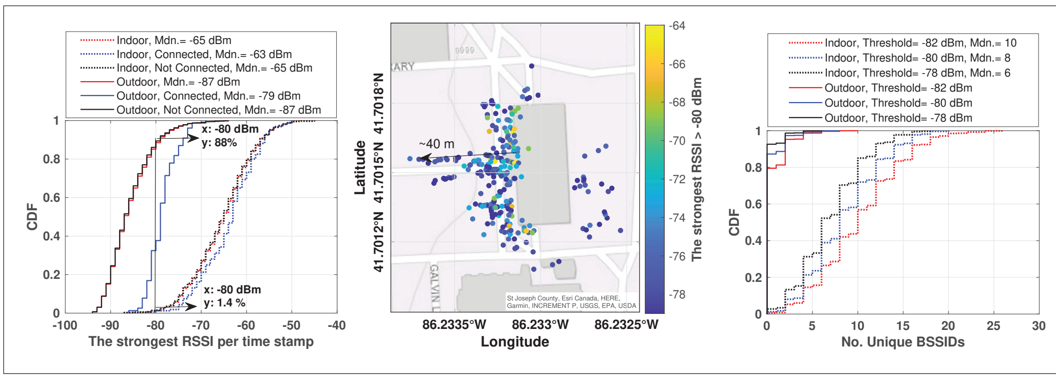

FIGURE 5. Evaluation of UND walking measurements for C2C connectivity at 6 GHz.

building at UND is 8 dB lower than the MCA, due to the low number of LPI Wi-Fi 6E APs.

The red pins given in the top figure of Fig. 3 shows the drone experiment locations, which were chosen due to their position over the path of fixed links in the UMich MCA. A smart phone running Sigcap was attached to a drone during the measurements. The middle figure of Fig. 4 shows a consistent decrease in both the number of samples and RSSI values with increasing altitude, where each color represents a different building (BLD). This trend alleviates the risk of interference on existing fixed links deployed at high altitudes. There exist a limited number of LPI APs performing line-of-sight (LOS) through windows, potentially resulting in higher outdoor RSSI values in very few specific locations. In many instances, elevated outdoor RSSI levels were measured within the vicinity of the buildings with low signal loss characteristics including historical structures and buildings with single-pane windows. The right figure of Fig. 4 shows the number of unique BSSIDs observed at different altitude levels. We observed a similar number of unique BSSIDs for the altitude levels of 0–20 m and 20–40 m. This number significantly decreased for the altitudes above 40 m, presenting lower risk of potential interference from Wi-Fi 6E LPI APs on the incumbents.

Analysis on C2C Communications in 6 GHz

Facilitating C2C mode for unlicensed 6 GHz wireless operations is an active area of research. In this mode, clients that receive an enabling signal from any 6 GHz LPI AP can establish direct communication among themselves. However, it is crucial to carefully adjust the level of the enabling signal to prevent outdoor client devices from inadvertently transmitting to each other.

Previously, we analyzed the RSSI of all the data collected, indoors and outdoors, without separating by time. To determine an appropriate enabling signal level for C2C communications, we need to determine the maximum RSSI received at each timestamp. With the rising adoption of Wi-Fi 6E technology, which operates in the 6 GHz frequency band, real-world deployment data becomes increasingly valuable, and can provide much-needed insights to guide the process of determining optimal signal levels for C2C communication in 6 GHz. Our data collection methodology enables us to gather the beacon RSSI from all BSSIDs measured every 5 seconds. Analysis of the beacon RSSI over 20 MHz offers insight into outdoor RSSI levels observed in a realistic setting, while the enabling signal proposed for C2C does not have to be the existing Wi-Fi beacon. An enabling signal level of -82 dBm/20 MHz is suggested in the recent proposals submitted to the FCC via the proponents [8].

The left figure of Fig. 5 shows the CDF plots of the measured RSSI indoors and outdoors for
1. When the device was connected to a BSSID,
2. When the device was not connected to a BSSID,
3. RSSI from all received BSSIDs.

As expected, the median RSSI is higher when the phone is connected compared to the RSSI received from all available BSSIDs. We observe a difference in median RSSI values of 2 dB indoors and 8 dB outdoors between connected and not connected measurements. This shows that most of the time, phones connect to the BSSID with the highest RSSI value in both scenarios. It should be noted that there are only a handful of connected outdoor samples where the device could maintain a connection with an indoor AP/BSSID. In this figure, we observe that if an enabling signal level of -80 dBm were chosen, only 1.4% of indoor devices would not be enabled, whereas only 12% of outdoor devices would be enabled. With a threshold of -78 dBm, these values are 3.2% and 7%, respectively, and with a threshold of −82 dBm, we have 0.6% and 20%, respectively. We believe that our methodology and analysis, grounded in real-world deployment data, offer a powerful tool for determining the optimal enabling signal level, minimizing the risk of interference to incumbent users in the 6 GHz band while simultaneously maximizing the potential for indoor devices to engage in seamless C2C transmissions. The middle figure of Fig. 5 shows that outdoor devices with a maximum RSSI greater than −80 dBm. They are very close to the building, particularly near the front entrance with double glass doors. Even if these outdoor devices are enabled for C2C transmissions, they are unlikely to pose any interference risk due to their close proximity to the building: these devices could have been connected to an LPI AP anyway and hence do not pose an increased interference risk if they engage in C2C communications. The right figure of Fig. 5 shows the CDF of number of unique BSSIDs that exceeds three distinct enabling signal thresholds: −78 dBm, −80 dBm and −82 dBm. The analysis reveals that the median number of unique BSSIDs received above the enabling signal threshold indoors is 6, 8, and 10 for the −78 dBm, −80 dBm, and −82 dBm thresholds, respectively. In contrast, the number of BSSIDs observed outdoor is notably lower. This result indicates that the probability of two outdoor devices being simultaneously enabled for C2C communication at any of these threshold levels is quite low. C2C operation can substantially enhance the performance of LPI Wi-Fi 6E and other indoor unlicensed devices while ensuring continued protection of incumbents. The presented results in this section present diverse evaluation methods utilizing different parameters collected via smartphones, offering a comprehensive exploration of 6 GHz spectrum sharing through real-world measurements.

Future Research Opportunities Using Device-Based Methodology

This section discusses how learning from deployed systems through detailed measurements is essential for advancing current strategies on spectrum sharing. We highlight key scenarios where the proposed methodology can be leveraged to address interference issues in emerging wireless communication technologies, with a specific focus on the co-existence of different technologies within the shared spectrum.

Leveraging Machine Learning (ML) for C2C Connectivity in 6 GHz

While the analysis of enabling signal thresholds provides valuable insights, we believe that an alternative approach leveraging ML and artificial intelligence (AI) tools holds significant promise for optimizing C2C operations in the 6 GHz band. By leveraging ML/AI tools, devices can autonomously determine their indoor or outdoor status, enabling more intelligent and adaptive C2C connectivity strategies. For smartphones, this identification process can leverage signal strength and the number of unique BSSIDs or cellular base stations (determined by PCI) received across all available radio interfaces 4G, 5G, Wi-Fi on all bands as well as GPS data. By combining these diverse data sources, ML/AI algorithms can accurately classify the device's environment as indoor or outdoor. The measurement methodology presented in this article can be readily adapted to collect the necessary data for training and validating such ML/AI models. Our past work [13] demonstrated that devices can use trained ML classifier models, like Random Forest, to robustly identify location: the premise is that these RF signals create an image, much like a photograph, which is quite different based on whether the device is indoors or outdoors.

Use of the Methodology in Cellular Networks

The need for additional spectrum resources and the potential for interference are not exclusive concerns for Wi-Fi based technologies. Similar work, though using more expensive professional tools such as Accuver XCAL, has been reported on characterizing performance of deployed 5G networks in terms of power consumption and application quality-of-experience (QoE) [14]. The study reveals key characteristics of 5G in terms of throughput, latency, and power consumption, offering insights into how mobile applications can best utilize 5G by balancing performance and energy consumption. As wireless cellular technologies continue to advance, introducing new services and applications, the demand for spectrum and the associated interference challenges are rapidly escalating across the entire wireless ecosystem. For example, in April 2015, FCC approved the Citizens Broadband Radio Service (CBRS) band, spanning from 3.55 to 3.7 GHz, for shared use by commercial wireless vendors, while ensuring protection from interference from the lower priority use in a hierarchical manner. Competing users in the same area lead to potential co-channel interference, limiting the performance of the coexisting wireless networks. Furthermore, the AMBIT band (from 3.45 to 3.55 GHz) and C-band (from 3.7 to 3.98 GHz), immediately adjacent to CBRS band, are allocated for exclusively licensed cellular systems with transmit power levels considerably higher than those of CBRS band. Thus, this represents a threat of adjacent channel interference (ACI) from AMBIT and C-band bands to users operating at the boundaries of the CBRS spectrum, negatively affecting the entire wireless ecosystem. The measurement methodology outlined in this article can be adapted to gather data information from cellular networks, such as RSSI, RSRP and Reference Signals Received Quality (RSRQ), which can then be subjected to thorough analysis. Outdoor RSRP heatmaps can offer valuable insights into signal coverage for various wireless systems operating in nearby areas, which can be exploited to relax potential interference between coexisting spectrum shared users. RSRQ data can help identify regions being exposed to potential interference alongside the PCI information. RSRP information can be leveraged to generate novel models of clutter loss associate to new frequency bands, and accordingly update the existing models with the environmental changes. The lessons learned can facilitate coexistence across the entire wireless ecosystem and open doors to new opportunities, growing as the number of coexisting use cases and applications continues to expand.

As wireless cellular technologies continue to advance, introducing new services and applications, the demand for spectrum and the associated interference challenges are rapidly escalating across the entire wireless ecosystem.

Scaling Up the Device-Based Methodology for Nation-Wide Survey of Wireless Networks

With ongoing 5G/NextG deployments, and the U.S. National Telecommunications and Information Administration (NTIA) announcing the exploration of new spectrum bands like the lower 3 GHz (3.1–3.45 GHz) and 7 GHz, continuous monitoring of network performance is vital for informed decision-making and future standards development. Therefore, a scaled up version of the device-based methodology is required to facilitate nationwide wireless network assessment. By partnering with undergraduate students across multiple universities in the SpectrumX group, we're building the infrastructure needed to streamline data collection and analysis on a large-scale [15]. Our current strategy involves distributing pre-configured measurement phones, utilizing a centralized data repository, and employing scripts and tools like ArcGIS for analysis. The resultant large-scale dataset will be publicly released, providing valuable insights for various research areas, including machine learning-based predictions for optimizing wireless networks.

Conclusions and Future Work

The contributions of this article are two-fold. First, we report first-of-a-kind, extensive measurements results and analyses from the a comprehensive measurement campaign of dense deployments of Wi-Fi 6E in 6 GHz in order to determine the impact on incumbents. The results of the analyses have been presented directly to the FCC to inform further regulatory actions in the band. We are continuing to leverage the growing deployment of Wi-Fi 6E at UND to study VLP and C2C operations. Second, we described our tools and methodology for conducting such studies rapidly: these can be used for many other measurement campaigns, in Wi-Fi and cellular bands, using smartphones. A sample of such work was described.

Such measurement campaigns on deployed networks can provide unique insights that are not often possible from purpose-built testbeds. For example, our 6 GHz measurements showed that only a very small percentage of Wi-Fi 6E APs (~5%) could be sensed outdoors, contradicting assumptions used in analyses which assumed a 20 dB building entry loss on every deployed AP. Our future work, using the tools and methodology described in the article, will continue measurements on both Wi-Fi and cellular bands.

Acknowledgements

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