Spectrum Utilization: Nationwide Measurements for New Spectrum Opportunities and Government Policy

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1. Introduction

The majority of usable RF spectrum is assigned to a wide variety of commercial, civil, federal, and military users. Yet vast amounts of this usable spectrum remains underutilized. Consequently, the current inventory of available spectrum cannot sufficiently address the emerging demand from consumers for our members' mobile and Wi-Fi networks. Left alone, this commercially available spectrum shortage will lead to congestion, service degradation, and churn among mobile and Wi-Fi customers.

Additional spectrum authorizations and technologies that enable more efficient use of spectrum will be needed in order to meet the intensifying demand for wireless data services. Before specific solutions can be identified, however, it is important to obtain a meaningful understanding of the utilization patterns in existing and candidate bands.

As part of the National Spectrum Strategy, the federal government identified a number of spectrum bands currently occupied by federal users that may be available for potential sharing with commercial uses, including 3.1-3.45 GHz, 7.125-8.4 GHz, and 37.0-37.6 GHz.

To help members understand the potential in these bands, CableLabs developed a low-cost, easy to deploy, remotely operated spectrum monitoring kit that can be used to collect spectrum usage data for bands up to 6 GHz. The platform pushes logged measurements to a cloud location where the data are analyzed and results displayed on a local dashboard.

To date, CableLabs has deployed the monitoring kit at its Louisville, CO location. Initial measurements targeted bands in the 3 GHz range, including 3.1-3.45 GHz, the Citizens Broadband Radio Service (CBRS) band which members are using for their own mobile and private wireless deployments as well as the 3.45 GHz and 3.7 GHz bands which are used for mobile and fixed wireless access services.

This paper will present the design of the spectrum monitoring kit, data analytics algorithm, and initial results. The monitoring platform has the potential to help our members assess the value of the spectrum under study within their markets, refine their wireless business case assumptions, develop spectrum advocacy strategies, and explore technical solutions for expanding their wireless services.

2. Measurement Campaign

The development of an effective spectrum monitoring system necessitates a comprehensive understanding of both the technical requirements and the design considerations. This section presents our proposed spectrum monitoring setup, measurement strategy, post processing results and explanation.

2.1. Spectrum Monitoring System

Figure 1 illustrates the experimental setup installed on the rooftop of our office building in Louisville, Colorado, USA. This suburban environment features an antenna positioned about 10 meters above the ground. The setup comprises several critical components to ensure accurate operation and data collection, listed below.

- At the core is the Signal Hound BB60C radio frequency (RF) scanner, chosen for its high reliability, sensitivity, and affordability. The scanner has a noise floor of -159 dBm/Hz and a noise figure of 15 dB.
- A 75-foot LMR-600 coaxial cable, noted for its low loss over long distances, connects the system components, resulting in a 3.75 dB loss.

- The antenna used is an L-com HG3509U-PRO, a vertically polarized 3.5 GHz 9 dBi omni-directional antenna, which offers broad coverage and reliable signal reception.
- To safeguard the equipment from lightning strikes, an L-com AL6-NFNFBW-9 lightning protector (LP) is included.
- Additionally, a Mini-Circuits ZX60-63GLN+ low-noise amplifier (LNA) can be optionally added to boost signal strength, providing a gain of approximately 27.8 dB at 3.5 GHz.

Data is processed and analyzed on a laptop. For system calibration, a matched load is used at various points: at the end of the RF scanner to measure its noise floor, at the end of the LNA to estimate LNA gain, at the end of the LP to measure LP loss, and at the end of the coaxial cable (substituting the antenna to block airborne signals) to assess cable loss and the overall system noise floor.

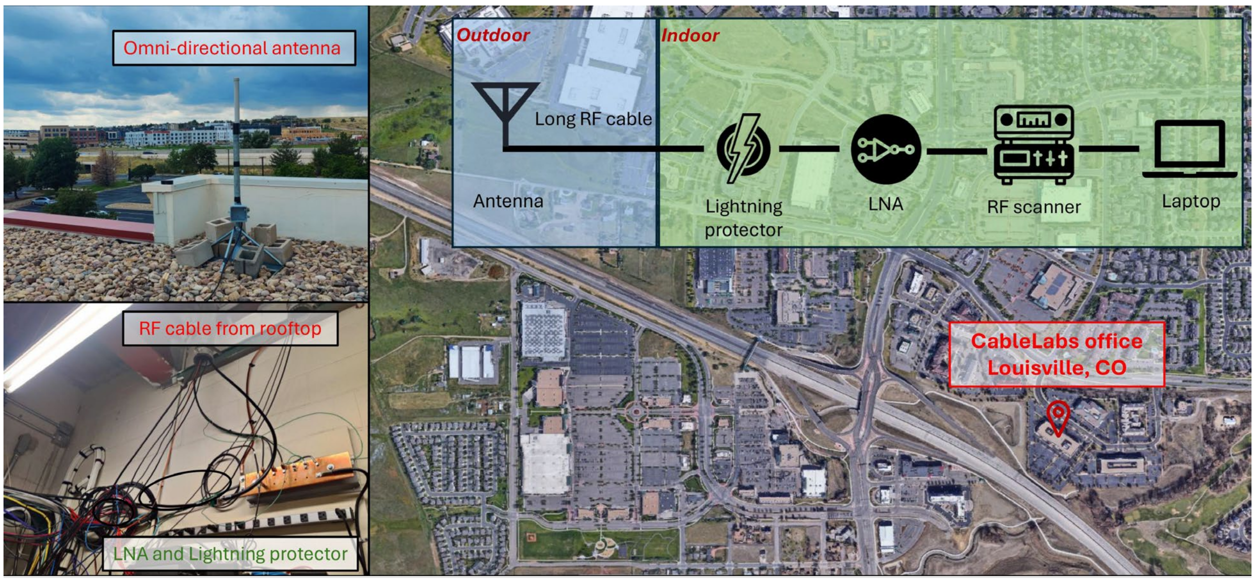


Figure 1 - Spectrum Measurement Setup at CableLabs, Louisville, Colorado, USA.

2.2. Measurement Approach

Spectrum usage monitoring is conducted across the 3.1 to 3.45 GHz frequency range, considered for mobile networks, with a 10 kHz resolution bandwidth (RBW). Continuous 24/7 data collection is facilitated by applying a -72 dBm/RBW power threshold, recording only signals above this level. This power threshold at the RF scanner translates to -105 dBm/RBW or -72 dBm/20MHz in the air, matching the power detection (PD) threshold used in the IEEE 802.11 Clear Channel Assessment (CCA) technique, also known as listen-before-talk (LBT), which indicates a channel is available for transmission.

Frequency, Unix timestamp, and signal power are recorded in Parquet format. The sweep time is set to 10 sweeps per second, but actual performance is limited to 4 to 5 sweeps per second due to constraints in the Fast-Fourier Transform (FFT) size, the number of frequency points, and the data transfer rate to the laptop via USB. The data volume ranges from 2 to 3 GB per day, depending on activity within the monitored frequency range. A trade-off exists between data volume and power threshold: a lower power threshold enhances sensitivity but significantly increases data volume. Table 1 summarizes the effect of power threshold on the number of measured data points and file size for three stored collected measurements. Each file contains the timestamp, frequency, power level, and other system parameters recorded during one minute of data collection. We will elaborate on this effect later in this section.

Table 1 - Example of power threshold and data volume trade-off

Date	Time (Mountain Time)	Num. of data points	File size (MB)	Power threshold (dBm)
June 20, 2024	16:51	23224446	315	No threshold
June 20, 2024	16:58	2228101	31	-80
June 25, 2024	15:58	402572	6	-72

2.3. Data Analysis and Metrics

To effectively analyze extensive data sets, we introduce two essential metrics: channel occupancy and airtime utilization. These metrics are pivotal for understanding the behavior and performance of mobile networks.

Channel Occupancy: For analysis purposes, the measured spectrum is divided into channels with bandwidth of ΔB, reflecting the typical channel allocation granularity in mobile networks, usually ranging between 5 and 10 MHz. For example, utilizing a 10 kHz RBW provides 500 data points in a 5 MHz bandwidth in a one-second sweep. A channel is considered "*occupied*" during any one-second period if it records one or more data points above the established power threshold (T). This indicates that the channel is not available for transmission under Clear Channel Assessment (CCA) criteria, which is crucial for preventing interference and ensuring efficient spectrum use.

Airtime Utilization: Airtime utilization measures the percentage of time a channel or frequency band is actively transmitting data relative to the total available time. For this analysis, "*airtime utilization per hour*" is calculated by the ratio of the total occupied seconds within an hour (3600 seconds). This metric provides insights into how extensively the spectrum is being used over time, helping identify patterns and potential openings for future commercial use.

2.4. Measurement Impacts to Metrics

Adjustments to critical parameters—such as channel bandwidth, power threshold, and measurement interval—can significantly influence these two metrics.

Channel Bandwidth: Changing the channel bandwidth can refine or broaden the analysis. Narrower bandwidths provide a more detailed look at specific frequency ranges, which is particularly useful for applications like narrowband IoT (NB-IoT) that operate with bandwidths as small as 200 kHz. In contrast, broader bandwidths can give a more general overview of spectrum usage.

Figure 2 illustrates the effect of channel bandwidth on airtime utilization across the frequency range of 3.1–3.45 GHz, between May 27 and June 3, 2024. Specifically, the figures compare airtime utilization for channel bandwidths of ΔB = 1 MHz, ΔB = 5 MHz, and ΔB = 10 MHz. As the bandwidth increases, the granularity of the data decreases, which is evident in the figures. Figure 2.a with ΔB = 1 MHz displays the most detailed fluctuations in airtime utilization, capturing fine-grained variations over time and frequency. Figure 2.b with ΔB = 5 MHz smooths out some of these fluctuations, providing a more generalized view of spectrum usage. Finally, Figure 2.c with ΔB = 10 MHz further generalizes the data, showing broader trends and overall utilization patterns. These comparisons highlight how different channel bandwidths impact the measurement and interpretation of spectrum usage, with narrower bandwidths offering more detailed insights and wider bandwidths providing a broader overview of utilization trends.

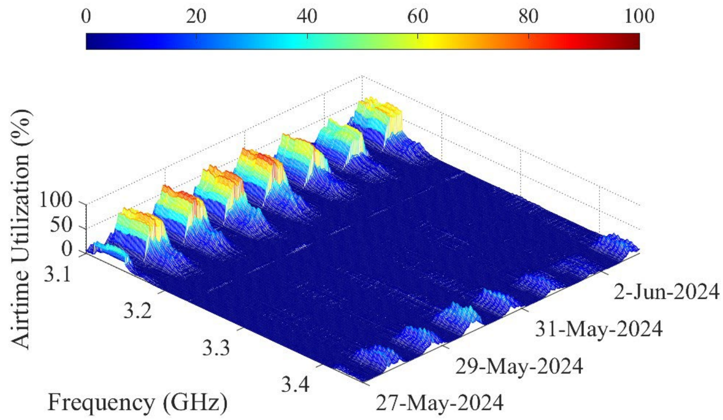


Figure 2.a ΔB = 1 MHz

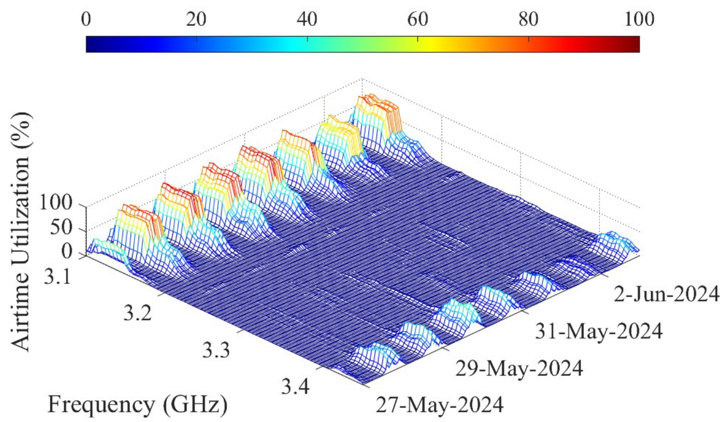


Figure 2.b ΔB = 5 MHz

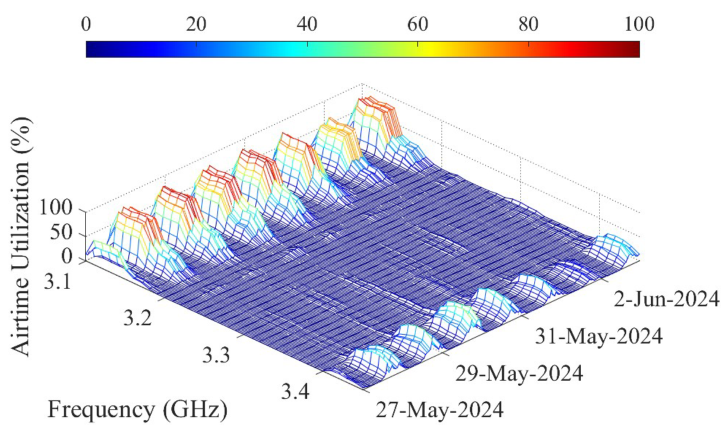
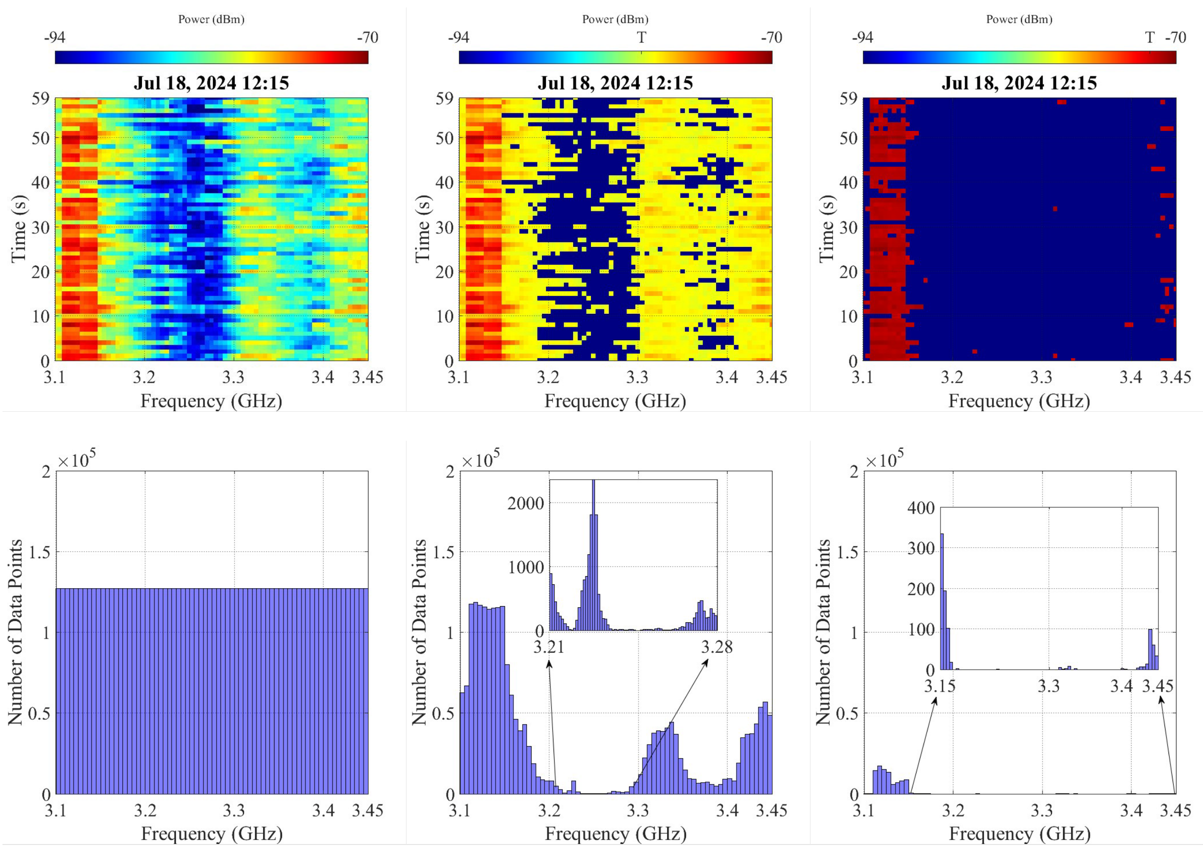


Figure 2.c ΔB = 10 MHz

Figure 2 - Effect of channel bandwidth on airtime utilizationacross the frequency range of 3.1–3.45 GHz, between May 27 and June 3, 2024, Louisville, CO.

Power Threshold: The power threshold determines the sensitivity of the measurement. Increasing the threshold imposes stricter criteria, meaning only stronger signals will be considered, thus reducing the reported airtime utilization. Lowering the threshold increases sensitivity, capturing more signals but also increasing data volume and potential noise.

Figure 3 shows the received power and the corresponding number of data points at 12:15 on July 18, 2024, over one minute. We have also considered two distinct power thresholds in Figures 3.b and 3.c, set at T = -80 dBm and T = -72 dBm, respectively. Figure 3.a represents the scenario without any power threshold applied. As shown in Figure 3, increasing the power threshold reduces both the resolution in received power and the number of data points. Notably, the data used in all subfigures is identical; these subfigures represent different methods of presenting the results. With a threshold of T = -72 dBm, the active region is primarily observed between 3.1-3.15 GHz, with sporadic occupancy throughout the remaining frequency range under consideration. It is important to note that these figures do not reflect the sensitivity of the measurement but rather the storage limitations and the methodology used in data handling.



Figures 3.a T= none ***Figures 3.b T = -80 dBm*** ***Figures 3.c T = -72 dBm***

Figure 3- Visualization of received power (top figures) and their corresponding number of data points (bottom figures) at 12:15 PM on July 18, 2024, over one minute for (a) no power threshold, (b) T = -80 dBm and (c) T = -72 dBm, Louisville, CO.

Measurement Interval: The duration of the measurement interval can significantly affect the granularity of the data. Shorter intervals capture more detailed fluctuations, leading to higher data volumes and potential noise. Conversely, longer intervals smooth out short-term variations, offering a more generalized view of spectrum usage. For example, extending the interval from one second to ten seconds can average out brief signal fluctuations, potentially overlooking short-duration bursts and thus altering the utilization rate.

In addition to varying measurement intervals, we can also present airtime utilization at different time resolutions. Figure 4 illustrates the airtime utilization across frequency bands from 3.1 GHz to 3.45 GHz during the week of May 27 to June 3, 2024, at both hourly and daily resolutions. As observed in Figure 4.a, airtime utilization fluctuates throughout the day, with higher values primarily between 8:00 AM and 8:00 PM. However, this level of detail is not evident in Figure 4.b, which shows the average airtime utilization for each day. While Figure 4.b is useful for comparing daily airtime utilization and highlighting differences between weekdays and weekends, it lacks the granularity needed to understand hourly variations.

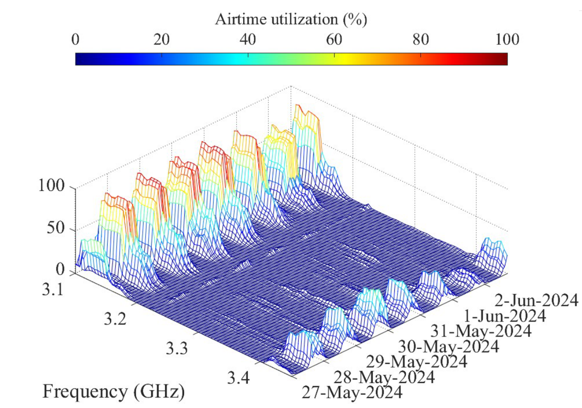


Figure 4.a Hourly Airtime Utilization

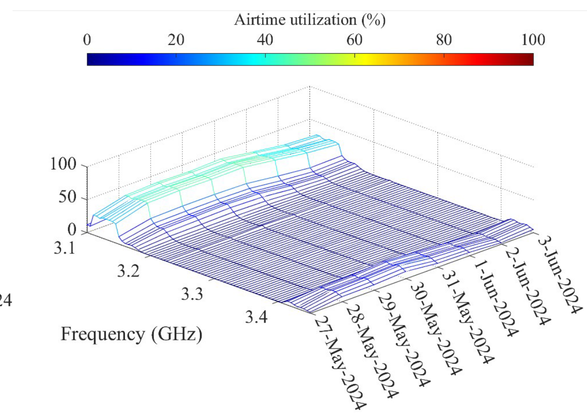


Figure 4.b Daily Airtime Utilization

Figure 4 - Airtime utilization across various frequency bands from 3.1 GHz to 3.45 GHz during the week of May 27 to June 3, 2024, Louisville, CO.

Based on the observations and our geolocation specifications, we conclude that a channel bandwidth of 5 MHz and a power threshold of -72 dBm are optimal for our analysis. This configuration provides a balance between detailed frequency range analysis and the ability to capture significant spectrum usage trends, thereby ensuring both accuracy and efficiency in our spectrum management strategy. In addition, this methodology provides sufficient data points in the airtime utilization calculation (i.e. 500 data points per 5 MHz channel bandwidth per one-second sweep) to be representative of the RF energy in that channel bandwidth with a high degree of confidence.

This approach allows for a comprehensive understanding of spectrum occupancy, facilitating effective planning and resource allocation. It is important to note that this approach measures only RF energy received at the measurement site. The approach does not account for specific waveform patterns, protocols, or other contextual information, making it an simplified measurement methodology.

2.5. Initial Results (Louisville, CO)

The airtime utilization metric described in the previous section produced results showing that use of the bands under study vary in time, both sequentially and aggregately. The sequential approach offers a way to review the data historically over time to generalize trends. While aggregate airtime utilization averages the airtime utilization over time to depict a more general utilization of the band that can help identify spectrum that has low or high utilization.

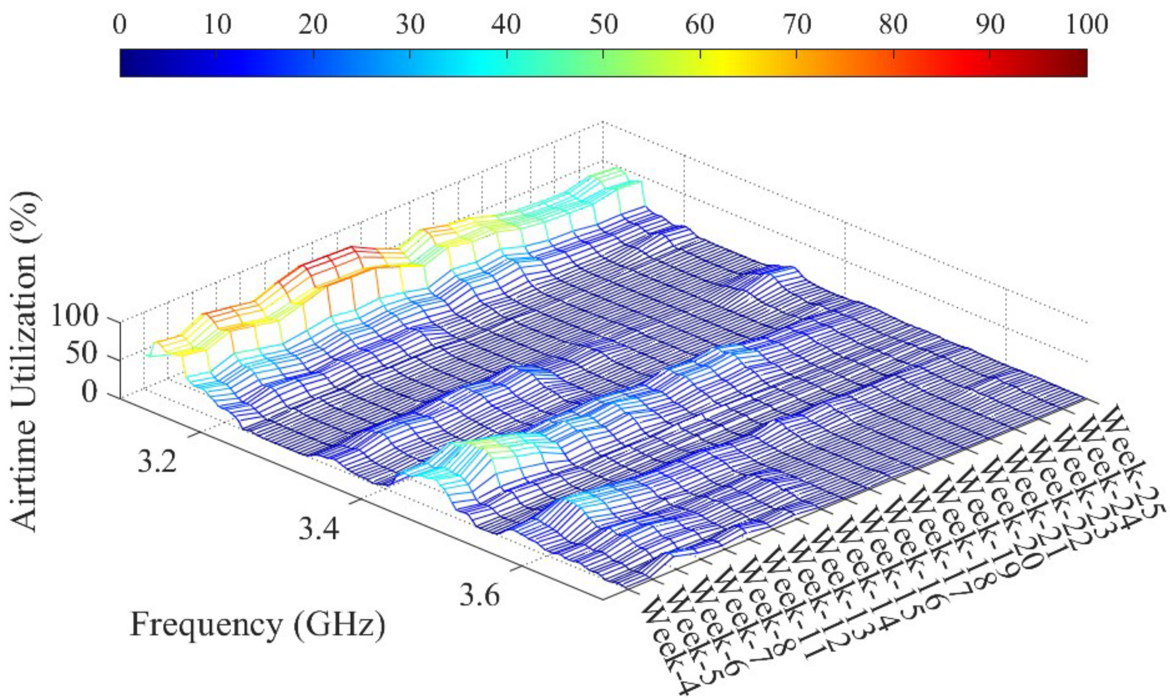


Figure 5 - Airtime utilization across different frequency bands (3.1 GHz to 3.7 GHz) over a 20-week period in 2024, Louisville, CO.

Figure 5 illustrates the airtime utilization across various frequency bands (3.1 GHz to 3.7 GHz) over a 20-week period in 2024. Note that "Week-4" corresponds to the period from January 21 to 27, 2024. The x-axis represents the frequency range, the y-axis denotes the weeks, and the z-axis indicates the average percentage of airtime utilization per week. The week numbers correspond to the weeks of the year starting from January 1, 2024.

Consistent patterns of utilization are observed across specific frequency bands over the weeks. The frequency range of 3.1–3.12 GHz consistently exhibits higher airtime utilization compared to other sections of the band, with peaks in weeks 12 and 13 where utilization exceeds 80%. The 3.4–3.5 GHz range also demonstrates significant peaks, particularly in week 6, where utilization levels approach 50% in the 3.435 to 3.445 GHz range. Other frequency ranges, such as 3.3–3.4 GHz and 3.6–3.7 GHz, show occasional increases in utilization during specific weeks but generally maintain lower levels compared to the 3.4–3.5 GHz range.

This visualization highlights temporal trends in spectrum usage, illustrating how certain frequency ranges experience higher demand during specific periods. Understanding these long-term patterns in airtime utilization is crucial to the analysis of potential for shared use of these bands. The consistent peaks during specific weeks suggest regular or scheduled activities that heavily utilize these frequency bands, providing valuable insights into the behavior of spectrum usage over time.

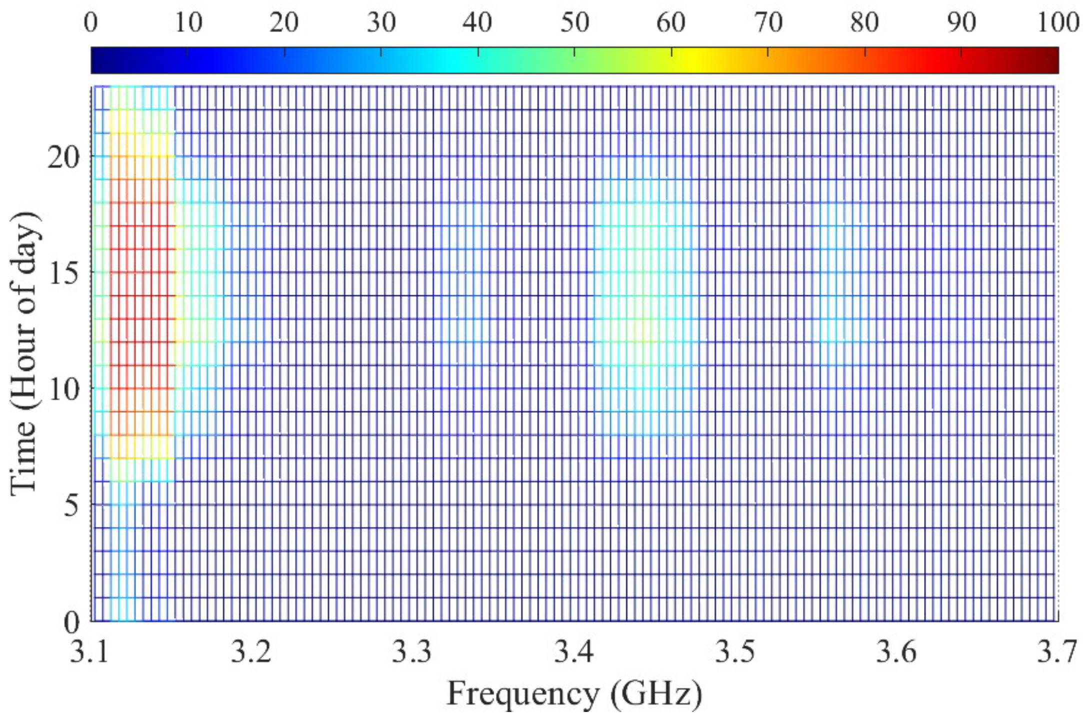


Figure 6 - Airtime utilization across frequency range of 3.1-3.7 GHz versus time of day, averaged over the measurement period from January 21 to June 17, 2024, Louisville, CO.

Figure 6 illustrates the airtime utilization versus the time of day over the measurement period from January 21 to June 17, 2024. The average airtime utilization for each hour of the day was calculated from the entire dataset to identify long-term trends. The x-axis represents the frequency range, the y-axis represents the time of day, and the color bar indicates the level of airtime utilization.

The frequency range of 3.1–3.15 GHz demonstrates higher activity levels compared to other ranges, as indicated by the red and orange colors. In contrast, other frequency bands exhibit significant activity predominantly during daytime hours, approximately between 8:00 AM and 8:00 PM, with peaks around 10:00 AM and 3:00 PM. Notably, the frequency ranges of 3.4–3.46 GHz and 3.55–3.57 GHz show observable activity during these hours, though their utilization levels are generally lower than those in the 3.1–3.15 GHz range, as evidenced by the lighter color shades.

These patterns suggest that the 3.1–3.15 GHz band is heavily utilized, potentially allocated for critical or continuous communication services, while other bands are likely used for activities that peak during regular business hours. This conclusion is drawn based on the location and threshold value considered in the analysis.

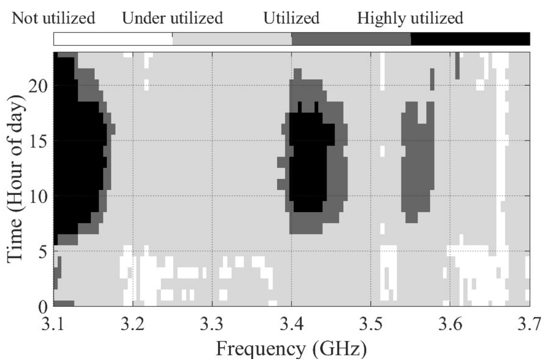


Figure 7.a May 1 to May 31, 2024

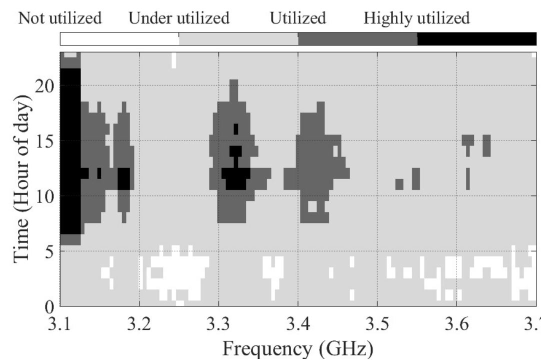


Figure 7.b June 1 to June 17, 2024

Figure 7 - Heatmap of maximum airtime utilization for frequency band from 3.1 GHz to 3.7 GHz over the period of (a) May 1 to May 31, 2024 and (b) June 1 to June 17, 2024, Louisville, CO, illustrating levels of airtime utilization: highly utilized (black, (50%, 100%]), moderately utilized (dark gray, (20%, 50%]), underutilized (light gray, (0%, 20%]), and not utilized (white, 0%).

Figure 7 illustrates heatmaps representing the maximum airtime utilization for frequency bands in the 3.1–3.7 GHz range over two time periods: (a) May 1 to May 31, 2024, and (b) June 1 to June 17, 2024. Using the maximum airtime utilization represents a conservative approach. The utilization levels are categorized as follows: black indicates highly utilized frequencies (airtime utilization higher than 50%), dark gray represents moderately utilized frequencies (airtime utilization between 20% and 50%), light gray signifies underutilized frequencies (airtime utilization between 0% and 20%), and white denotes frequencies that are not utilized (airtime utilization equal to 0%).

As shown in Figure 7.a, the frequency range between 3.1 GHz and 3.17 GHz is heavily utilized, particularly from 7 AM to 10 PM, indicating consistent demand during these hours. In contrast, the bands around 3.4 GHz to 3.48 GHz and 3.54 GHz to 3.58 GHz generally show intermittent utilization, with less consistency and lower overall usage compared to the 3.1 GHz to 3.17 GHz range. Notably, the frequency bands between these highly utilized regions, specifically around 3.17 GHz to 3.4 GHz and 3.58 GHz to 3.65 GHz, remain largely underutilized. Additionally, certain portions of the spectrum, such as 3.66 GHz to 3.67 GHz, exhibit zero airtime utilization for most of the day. In contrast, Figure 7.b reveals increased activity around the 3.3 GHz spectrum in June compared to May, while the 3.4 GHz band is no longer heavily active. This visualization is crucial for understanding spectrum occupancy patterns and can inform more efficient spectrum management and planning strategies.

Our analysis of airtime utilization across the frequency range of 3.1 GHz to 3.7 GHz reveals significant trends and patterns that can be viewed on an hourly, daily, weekly, and monthly basis, depending on the objective of the investigation.

2.6. Extended Measurement Campaign

The overall objective of the measurement campaign is to extend spectrum monitoring systems to multiple geographic locations across the United States to obtain geographical diversity in measurements. To support this effort, CableLabs built a data platform that pushes local logged measurements to a cloud location where the data are analyzed and results displayed on a local dashboard as shown in Figure 8.

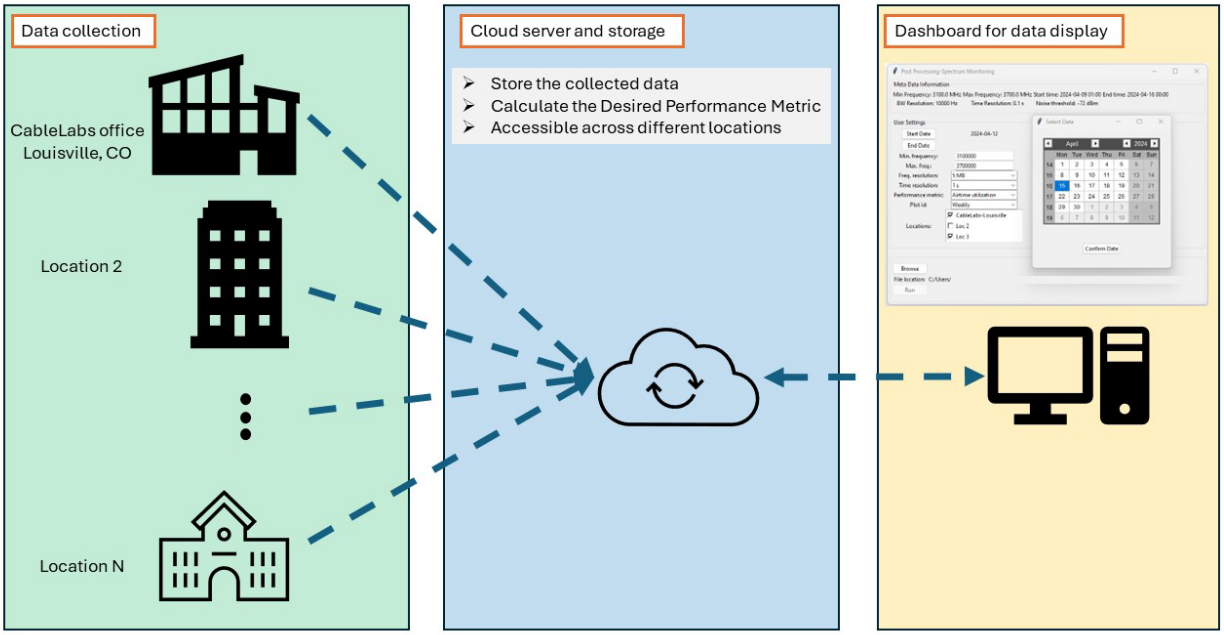


Figure 8 - Spectrum Monitoring logging and analysis platform

This platform provides members, academia and industry the opportunity to collect data and utilize the data analytics software and analyze the data on a dashboard. The dashboard is accessible by approval and allows users to compare general trends of spectrum utilization per frequency, location, and time.

3. Application of Results

This spectrum monitoring approach allows for the manipulation of measurement settings and data metrics to provide varying levels of analysis detail. For example, as described in earlier sections, airtime utilization can be viewed on an hourly, daily, and weekly basis or the channel bandwidth can be adjusted between 1 to 10 MHz to provide granularity in the results. This enables a variety of stakeholders the freedom to use the data for their own customized research and purposes. For instance, airtime utilization can be used as general research by operators to monitor unlicensed, licensed or shared spectrum. This can assist in assessing interference, congestion, and operational aspects of wireless network management. Two additional stakeholders that may use this data include academia and policy experts.

3.1. Academia

Academia address areas of spectrum research that includes RF data collection, spectrum sharing modeling/simulation and dynamic spectrum sharing techniques. The spectrum monitoring system and data collection can be used by academia as an enhancement or complementary means to their research. Collected data can be used by and shared with academia to validate academia-developed models and simulation tools that predict spectrum sharing. In addition, the entire measurement campaign utilizing multiple geographic locations can be used to develop dynamic spectrum sharing technologies and techniques. The data metrics of channel bandwidth, power threshold, and measurement intervals that impact airtime utilization can all be used by the academic community as part of their research.

3.2. Regulatory Policy

Policy experts can use the spectrum monitoring system and airtime utilization results to make recommendations to policymakers that would enable dynamic spectrum sharing in the bands identified by the Federal government. This can include spectrum sharing techniques, identifying under-utilized spectrum on a time, location and frequency basis, and power level thresholds to protect incumbents. For example, the airtime utilization results across a frequency range on a weekly basis over 20 weeks (Figure 5) and airtime utilization across frequency range versus time of day averaged over 20 weeks (e.g. Figure 6) can be used to demonstrate trends in spectrum utilization per geographic location and likely success of spectrum sharing.

4. Alternative Spectrum Measurement Methods

In data collection, two main methodologies are utilized to achieve different levels of detail and informational requirements. The first method employs commercial off-the-shelf radio equipment, such as Android phones running over-the-top (OTT) applications. These devices effectively gather key performance indicators, including reference signal received power and quality (RSRQ), along with other relevant radio and network data. However, their use is limited to specific frequency bands and signal sources, restricting their ability to collect data beyond these parameters. For instance, Sathya et al. In [1] present a comprehensive measurement campaign of LTE-Licensed Assisted Access (LAA) deployments in Chicago, highlighting the coexistence challenges between LAA and Wi-Fi in dense urban environments. The findings reveal that while LAA effectively utilizes unlicensed spectrum, its interaction with existing Wi-Fi networks requires further research to ensure fair coexistence and optimal network performance.

The second methodology involves using spectrum monitoring equipment capable of continuous observation and analysis across a wide frequency spectrum. This equipment excels in identifying both expected and unexpected emissions over broad frequency ranges, providing a comprehensive view of the spectral environment. Such capabilities are crucial for pinpointing interference sources, complying with regulations, and improving network performance through insights into spectral efficiency and utilization. For example, Tschimben et al. in [2] conducted outdoor Wi-Fi power measurements across the University of Colorado Boulder campus using software-defined radios (SDRs) and GNU Radio. Their research demonstrates the viability of low-cost SDR platforms for spectrum monitoring and highlights their potential for broader applications in spectrum utilization analysis, particularly with proper calibration and hardware design. In another study [3], Cotton et al. performed a detailed analysis of spectrum occupancy in the 3.45–3.65 GHz range through long-term measurements at four coastal sites in the U.S. This study provides valuable insights into the usage patterns of this spectrum band, emphasizing the varying levels of occupancy observed across different locations and time periods, thereby informing the feasibility of spectrum sharing between federal and commercial users. Using Helikite, the Aerial Experimentation and Research Platform for Advanced Wireless (AERPAW) group conducted altitude-dependent spectrum measurements using the AERPAW platform, highlighting key observations on spectrum occupancy variations based on altitude, environment, and transmission direction [4]. The findings underscore the importance of 3D spectrum measurement for developing effective spectrum reuse techniques and offer recommendations for future research and the implementation of the national spectrum strategy. More recently, [5] introduces an innovative spectrum measurement setup and the airtime utilization metric to quantify spectrum usage. The design provides a protocol-independent solution for detailed spectrum analysis across frequency, time, and power dimensions, essential for effective spectrum management. Extensive measurements in the 3.1 to 3.7 GHz frequency range demonstrate the practical application of the setup, revealing significant underutilization in certain bands and highlighting opportunities for dynamic spectrum sharing.

The summary of these studies is provided in Table 2.

Table 2 - Summary of the most relevant works and their specifications

Ref.	Measurement device	Environmental configuration	Target frequency range	Measurement metrics	Experiment duration
[1]	Android app (SigCap)	Chicago, IL – Outdoor	5.15-5.85 GHz	key performance indicators	Several months
[2]	SDR (USRP B200 mini-i)	CU Boulder campus – indoor and outdoor	2.426-2.448 GHz (Wi-Fi Channel 6)	I/Q data	Four weeks
[3]	Signal analyzer (Keysight N6841A)	San Diego, CA; Norfolk, VA; San Francisco, CA; and Astoria, OR – Outdoor	3.45-3.65 GHz	Power	Two years
[4]	SDR (NI USRP B205mini)	Raleigh, NC – Outdoor	Sub-6 GHz	Power	Few hours
[5]	Signal analyzer (Signal hound)	Louisville, CO – Outdoor	3.1-3.7 GHz	Power	Several months

5. Conclusion

In conclusion, this study underscores the critical role of innovative spectrum measurement techniques and the introduction of the "airtime utilization" metric in refining spectrum management strategies. This technique offers reliable measurement of spectrum utilization in time, frequency and location. It also allows for the manipulation of measurement settings and data metrics to provide varying levels of analysis detail. This enables a variety of stakeholders the freedom to use the data for their own customized research and purposes.

Measurement impacts to airtime utilization and channel occupancy metrics were analyzed, such as channel bandwidth, power threshold, and measurement intervals. Based on the observations and our geolocation specifications, we conclude that a channel bandwidth of 5 MHz and a power threshold of -72 dBm are optimal for our analysis. This configuration provides a balance between detailed frequency range analysis and the ability to capture significant spectrum usage trends, thereby ensuring both accuracy and efficiency in our spectrum management strategy. In addition, this methodology provides sufficient data points in the airtime utilization calculation to be representative of the RF energy in that channel bandwidth with a high degree of confidence.

Utilizing the airtime utilization metric, results are shown using variations in time, both sequentially and aggregately. These approaches offer a way to review the data historically over time to generalize trends using different graphs. Such graphs include airtime utilization across a frequency range (1) over a 20-week period (2) across time of day and (3) a heatmap of different levels of airtime utilization across time of day.

Our findings from extensive measurements across the 3.1 to 3.7 GHz frequency range reveal significant insights into spectrum dynamics, demonstrating the efficacy of our setup in real-world applications. The results highlight the potential for more efficient spectrum utilization through advanced monitoring and analysis tools.

Future research will focus on expanding our measurement framework to various locations and broader spectra and integrating more granular and longer-term data analytics to further enhance the precision of spectrum allocation and policymaking. This endeavor will contribute to maximizing the utility of this scarce resource, ensuring more effective communication technologies and better service delivery across various sectors.

Abbreviations

CBRS	Citizens Broadband Radio Service
CCA	Clear Channel Assessment
FFT	Fast Fourier Transform
GHz	Giga-Hertz
LBT	Listen Before Talk
LNA	Low Noise Amplifier
LP	Lightning Protector
PD	Power Detection
RBW	Resolution Bandwidth
RF	Radio Frequency
SCTE	Society of Cable Telecommunications Engineers

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