Pathloss Analysis of CBRS Network using UE-based Measurements

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1 Introduction

Mobile network planning relies on use of empirical propagation models whose development rely on measurements obtained in controlled measurement campaigns using high-fidelity equipments. However, the applicability of site-specific analysis in real-world deployments are not possible when using these models, as the measurements used to develop these models often cannot be translated onto a different environment. Alternatively, methods that consider site specific information – such as ray tracing and native machine learning (ML) integration – are being heavily researched on, however, these approaches face challenges such as high computational demands and limited generalizability, respectively [1, 2]. To address these limitations, the broader theme of this work is to utilize user equipment (UE)-measured network parameters, in particular, the Reference Signal Received Power (RSRP) metric, to inform the mobile network planning process. While this approach enables use of measurements tailored to specific deployment sites, it also carries the risk of providing incomplete or inaccurate data at certain locations, potentially misrepresenting network performance and introducing bias in the collected samples.

The key objectives and anticipated findings for this project are outlined below:

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1. *CBRS deployment measurements*: We plan to investigate the deployment configuration and parameters of South Bend's private CBRS network. This effort aims to design measurement campaigns that capture key performance indicators (KPIs) to evaluate the performance of a real-world deployment effectively.

2. *Coverage prediction*: Building on the collected measurements, we plan to incorporate proprietary deployment specifications provided by the infrastructure company to extract parameters (such as distance, RSRP, transmitter (Tx) power, etc.) for training models to predict network coverage.

2 Preliminaries

2.1 Definitions - RSRP as a Predictor

Propagation Path Loss (PL) (defined as the logarithmic measure of the decrease in signal strength between a transmitter and a receiver, typically expressed in decibels (dB)) models are used to predict the coverage of a given network initially, and then engineered for capacity. These models take various key system parameters as its inputs – such as transmitted power, frequency, antenna height, etc. The received signal power (P_{Rx}), calculated as the transmitted power minus the path loss ($P_{Tx} - PL$) – decreases as a receiver (or termed as UE) moves away from a transmitter – this is known as signal attenuation. Physics-based modeling of electromagnetic wave propagation through free space indicates that attenuation is proportional to the square of the distance ($\propto d^{-2}$). However, real-world deployments deviate significantly from ideal free-space conditions, as the density of obstructions along the signal path can vary greatly depending on the specific site and receiver location. Literature reveals that real world can vary up to the fourth or fifth power in denser urban areas, especially when inside a building.

Among the various metrics measured by User Equipment (UE) to make critical network-related decisions and maintain connectivity, one key metric used to represent the strength of the received electromagnetic signal is RSRP. In our study, we will primarily use RSRP as the definition of coverage and design our model to predict RSRP based on other relevant parameters influencing this prediction.

2.2 Access to High-Quality Data

Telecom infrastructure deployers and related entities often keep the details of their deployments highly confidential due to the substantial costs associated with spectrum and the immense $2T industry it supports. This secrecy helps maintain a competitive advantage and safeguards proprietary business strategies. However, the Federal Communications Commission's (FCC) recent management of the Citizens Broadband Radio Service (CBRS) band (3.55-3.7 GHz) has introduced a transformative approach by enabling spectrum sharing among multiple players. This allows smaller entities, including mid-sized companies, educational institutions, and non-traditional telecom players, to operate and transmit simultaneously within the same band without incurring the prohibitive costs of exclusive licenses. Many of these new entrants are leveraging this opportunity to deploy private networks and are increasingly willing to collaborate on research and development projects. Collaborating with a private provider for the City of South Bend CBRS deployment has been instrumental in enabling us to gather a highly accurate and detailed dataset to address this problem effectively.

3 South Bend CBRS Deployment

The CBRS deployment in South Bend, shown in Fig.1, includes four transmission towers, referred to as base stations (BS). Each BS serves multiple sectors radiating from its location, identified by their respective Physical Cell Identifier (PCI), as depicted in Fig.1. To prevent interference from transmitting at the same frequency and to enable frequency reuse, the entire CBRS band (3.55–3.7 GHz) is divided into 20 MHz channels. The deployer is licensed to use several of these channels, centered at 3560, 3580, 3640, 3670, and 3690 MHz, also illustrated in Fig. 1. The fundamental principle of frequency reuse is that sectors operating on the same frequency should not overlap to avoid interference.

However, an overlap is observed between BS-3 PCI-51 and BS-4 PCI-18. Although mechanisms exist to mitigate interference, they are beyond the scope of this report. It is important to note that this deployer is not the sole entity contending for the spectrum and must also ensure their sectors do not interfere with those of other operators. Achieving a completely interference-free solution under such conditions is virtually impossible. Their deployment

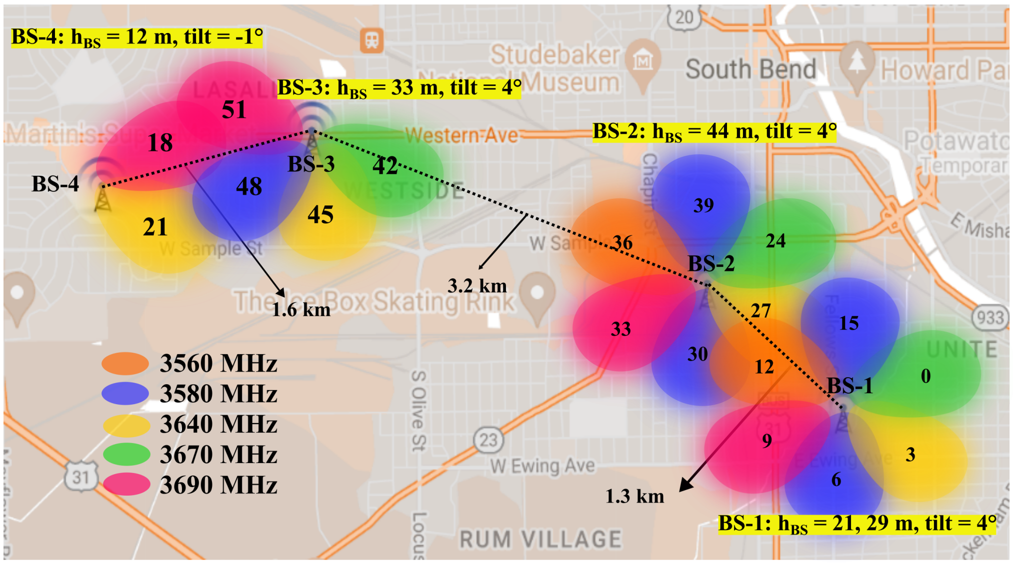

Figure 1: Network deployment layout (numbers represents PCIs)

configuration represents an optimized compromise, balancing spectrum allocation and planning constraints, which may explain the apparent inconsistency in frequency planning for overlapping PCIs.

4 Methodology

Measurements were collected using a Samsung Galaxy S22+ User Equipment (UE), carried by the measurer while traversing all accessible roads around BS-3 and BS-4. The measurement methodology is illustrated in Fig. 2. The primary device, referred to as Phone-1, was used exclusively for this deployment's measurements, while additional devices were employed to monitor other operators for advanced analysis and comparison in future studies.

The parameters collected during the measurement campaign relevant to this analysis are described as follows:

1. GPS coordinates: While traversing the area, the UE recorded the latitude and longitude coordinates corresponding to each measurement location.

2. PCI: The connected PCI of the sector from which the measurement

Figure 2: Methodology used for measurement campaign

value was obtained was logged.

3. RSRP: The RSRP, representing the signal strength received from the connected PCI, was recorded.

The following metrics were calculated after processing the measurements captured by the UE (the Python scripts for these functions are included in the `\final_project\python` folder):

1. Distance between UE and BS: The Haversine formula, as given below, was used to calculate the distance between two GPS coordinate locations:

$$d = 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\alpha_2 - \alpha_1}{2}\right) + \cos(\alpha_2)\cos(\alpha_1)\sin^2\left(\frac{\beta_2 - \beta_1}{2}\right)}\right) \quad (1)$$

   where, r is the radius of the earth (at South Bend), (α_1, β_1) and (α_2, β_2) are the latitude-longitude coordinates of the base stations and the UE locations.

2. UE Location Bearing: The bearing or azimuth angle of the UE relative to the sectors orientation was calculated using the GPS coordinates of UE, and the sectors orientation. This angle indicates the direction of the UE concerning the sector it is connected to and serves as an essential parameter for further antenna calculations.

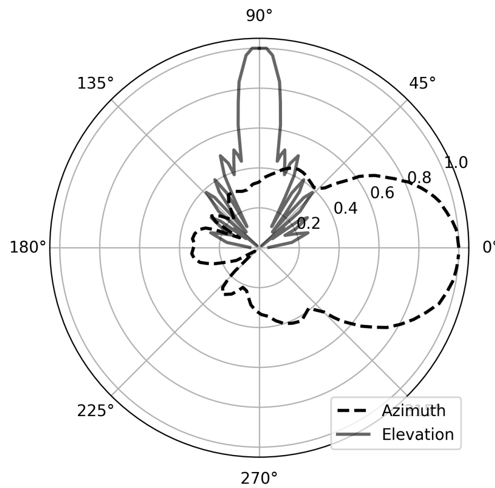

Figure 3: Transmit Antenna directivity pattern

3. Antenna Directivity Pattern: The antenna gain is influenced by its directional gain patterns, which vary based on the azimuth and elevation angles (see Fig. 3). By utilizing the UE location bearing, the relative position of the UE with respect to the antenna's orientation is determined. This information is used to calculate the effective gain applied to the signal, ensuring that signal strength measurements account for the antenna's directional characteristics.

5 Data Analysis

Violin plots were generated to evaluate the deployment performance in terms of connectivity. From Fig.4, it is evident that BS-3 connects with UEs at greater distances compared to BS-4, which has a maximum effective range of approximately 1 km. This difference can be attributed to the heights of the base stations, as seen in Fig.1. BS-3 is positioned at a height of 33m, significantly higher than BS-4, which is at 12m. Higher antenna placement offers increased coverage but comes at the expense of higher transmit power requirements. This is corroborated by Fig. 5, where BS-3 consistently operates with higher power levels compared to BS-4.

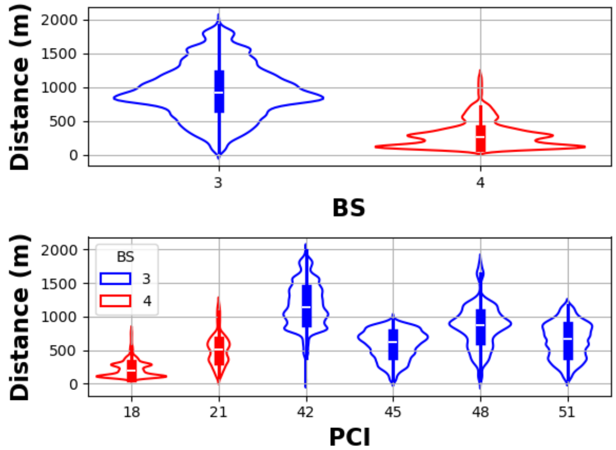

Figure 4: Violin plot showing the distribution of distances between the UE and the BS, PCI it connected to.

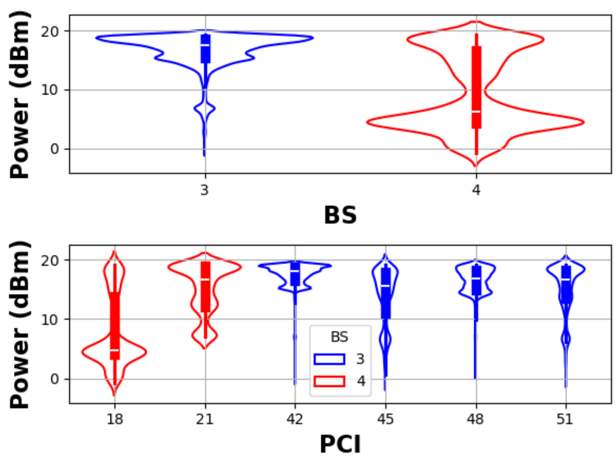

Figure 5: Violin plot showing the distribution of power usage at the BS, PCI to connect to the UE.

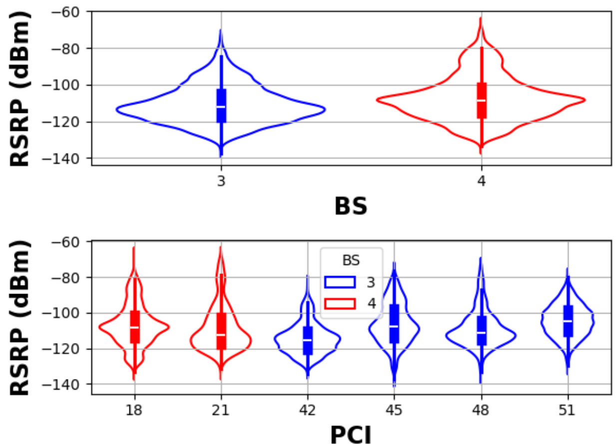

Figure 6: Violin plot showing the RSRP distribution from BS, PCI, measured at the UE.

Despite the height advantage and increased power usage of BS-3, no significant difference in RSRP (signal strength received by the UE) is observed between the two base stations, as illustrated in Fig. 6.

This analysis highlights a trade-off in base station deployment strategies. Deploying shorter towers conserves power resources but provides limited coverage. Conversely, taller towers increase coverage but require higher power, resulting in increased operational costs. Furthermore, deploying numerous low-height towers involves high installation costs, while relying on fewer tall towers drives up power expenditure. As is often the case in engineering, there is no perfect solution—each approach involves trade-offs depending on specific deployment goals and constraints.

6 Modeling to Predict

A simple four-layer dense neural network model was used to address the primary question: Does including UE GPS coordinate information during training improve coverage prediction? The results indicated a difference of approximately 1.3 dBm in mean absolute error (MAE), suggesting a minor improvement. However, this difference is negligible given the simplicity of the model, which may not fully capture the potential impact of including GPS coordinates. Additionally, the study was conducted on a small-scale deployment with a limited set of PCIs, which could constrain the findings. Further research with more complex models and larger deployments is required to draw more definitive conclusions on the value of GPS coordinate information in coverage prediction.

The Jupyter notebook used for training and testing this model is available in the file `\final_project\notebooks\code6_learning.ipynb`.

7 Conclusion

This report examined the performance and characteristics of a private CBRS deployment in South Bend by leveraging UE-measured data and analyzing key metrics such as distance, RSRP, and power usage. The findings highlight several trade-offs in deployment strategies, including the balance between tower height, coverage, and power efficiency. While taller towers provide greater coverage, they come at the cost of increased power consumption, whereas shorter towers conserve power but limit the range. These trade-offs underline the complexities of designing optimal deployment configurations, especially in shared spectrum environments like CBRS.

Additionally, a simple neural network model was used to explore whether incorporating UE GPS coordinates improves coverage prediction. Although the results showed a marginal improvement, they underscore the need for further research using more sophisticated models and larger-scale deployments to validate the potential benefits of site-specific data.

This work demonstrates the value of UE-measured data in informing network planning, while also emphasizing the limitations of small-scale studies and simple models. Future efforts should focus on expanding the dataset and integrating advanced modeling techniques to further enhance the effectiveness and reliability of CBRS networks. By doing so, it will be possible to make more robust and scalable predictions that can better inform deployment strategies in real-world scenarios.

References

[1] J. Hoydis, S. Cammerer, F. A. Aoudia, A. Vem, N. Binder, G. Marcus, and A. Keller, "Sionna: An open-source library for next-generation physical layer research," *arXiv:2203.11854*, 2022.

[2] J. Ethier and M. Chateauvert, “Machine learning-based path loss modeling with simplified features,” *IEEE Antennas and Wireless Propagation Letters*, 2024.