CS438: Wireless Project Towards Thomas M. Siebel Center

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ABSTRACT

This article presents a comprehensive study on wireless network analysis with a focus on Wi-Fi access points (AP) roaming mechanism and signal strength heatmap generation. Recognizing the limit of existing Wi-Fi analyzer applications, we developed an open-source, Python-based mini tool to create the Wi-Fi coverage map. The tool is designed using procedure-oriented data pipeline architecture, including coordinate construction, data collection and data prepossessing, heatmap generation, and single AP analysis. The methodology outlined in this paper demonstrates the tool's utility in practical applications, offering insights into AP roaming mechanisms and signal strength distribution. The project's goal is to practice our knowledge in real-world environments. Based on the cooperation with UIUC IT Network team, the project provides a series of observation and suggestion on the campus network.

KEYWORDS

Wireless Network, Heatmap, AP Roaming, Open-source Tool

1 INTRODUCTION

This project aims to apply the principles and knowledge derived from our CS438: Communication Networks course to real-world scenarios. We are interested in analyzing the Wi-Fi access point arrangement at Thomas M. Siebel Center with what we learned about wireless network from CS438.

After evaluating several well-known Wi-Fi analyzer applications such as Netspot and Wifiman, we found that these platforms fail to provide explicit data required for in-depth analysis[7]. Furthermore, their scope and performance are unable to meet our research needs. As a result, our group has developed an open-source, python-based Wi-Fi analyzer tool[4], which is both comprehensive and adaptable. This tool's usage and performance in its practical applications as discussed in the methodology section of this paper.

2 BACKGROUND

In a single building wireless network scenario, optimal Wi-Fi performance is heavily reliant on the appropriate design, configuration, and maintenance. An important aspect of maintaining high-quality Wi-Fi performance is the continual monitoring and analysis of network performance. Signal strength, for instance, is a vital factor that can mainly decide Wi-Fi performance. Lower signal strength from an access point (AP) can lead to a lower Signal-to-Noise Ratio, causing a higher bit error rate.

Today, Wi-Fi signal measurements often utilize signal strength heatmaps, which are efficient in providing a visual representation of signal strength across a particular area. Several heatmap tools are available on the market, but these tools have two main problems: Firstly, most of these tools create a heatmap based on the AP with the highest received signal strength indication (RSSI). However, the reality is that the AP a user connects to may not be the AP with the highest signal strength due to Wi-Fi roaming mechanisms. Secondly, most of these tools are not free and open-source, the scope of detailed data information is hidden, which can't provide accurate information for our measurement [5].

The UIUC IT Network department currently uses Aruba software to generate the visual representation of RF coverage. Similar to a signal strength based heatmap, It combines the floor plans and installed access points to create a graphical representation of Wi-Fi coverage [1]. However, this heatmap is not based on actual measurements but rather on the ideal signal strength of each AP, which may not accurately reflect the actual signal strength.

Currently, there are two main WiFi across the campus: illinois Net and Eduroam. Each is associated with hundreds of connected-routers, which constructed as a wide Campus Area Network(CAN). The Our intuitive interest focus on the mechanism of it. Based on the knowledge we learned in CS438, we plan to investigate how different Access Points (AP) work and the AP roaming mechanism in practice.

Given these issues, our group has developed a new heat map tool that generates a Wi-Fi signal strength heatmap based on the AP the user is connected to, aligning more closely with real-world scenarios. We then apply this tool to analyze signal strength and identify poor performance areas for improvement.

3 METHODOLOGY

3.1 Intuition

After testing and comparing other network coverage mapping software, we have gained an understanding of the tool architecture for heatmap generation through a review of related literature[3, 5, 6]. Based on this, we designed the following data pipeline:

(1) **Coordinate Construction**: Establish a coordinate system based on the floor plan image.
(2) **Data collection**: perform multiple scans at hundreds of points on the map, confirm the router ID currently connected to, and import the data into raw_data.csv.
(3) **Data cleaning**: Average the signal strength of each AP at each test point and categorize the APs by BSSID, exporting them to different BSSID.csv files. Record the AP connected. The one-hop row represents the actual signal strength experienced by the user when moving within the building. Compile this data into preprocessed_mean.csv.
(4) **Heatmap generation**: Based on the coordinate system, we use algorithms like Rbf for interpolation between test points. Considering that the accuracy of the grid method heatmap is not high enough, we chose a circular heatmap that has smoother curves and a coverage range closer to the actual Wi-Fi signal broadcast.

(5) **Analysis**: The goal of the analysis is to evaluate the reliability of our measurement and network performance via these APs.We use statistical methods to find the frequency of occurrence of each AP in our measure, their average signal strength, and the number of test points they are related to. This provides a holistic understanding of the performance of individual APs and their impact on the overall network performance.

The project code usage is recorded in tool_notebook.ipynb. Preparing the corresponding floor plan, one can follow the instruction to create the new map easily. Encountered problems during the tool construction are recorded in /Tool/buglog.md, which may be helpful to other researchers. The open-source code has removed privacy resources such as school APinfo, and the data folder only contains filtered data. For further need to view the details, please contact the Network team by email. Since the Siebel Center's Floor Plan is public, we have retained it.

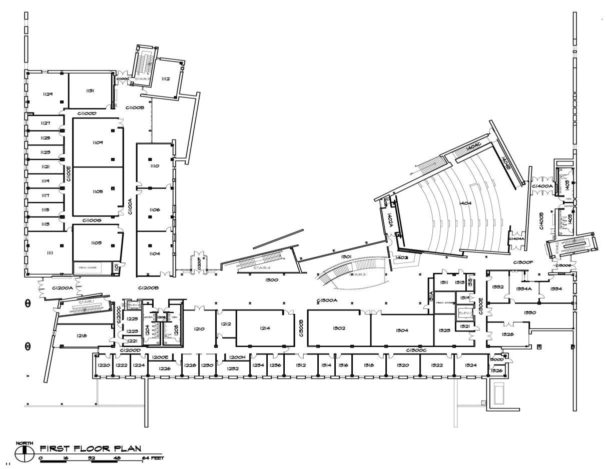

Figure 1: Thomas M.Sieble Center First Floor Plan

3.2 Implementation

Coordinate Generation In order to do precise and reliable measurement on the Siebel Center, we need a high-resolution floor plan for it. We downloaded a floor plan from open-source and used "matplotlib.ticker" library to get the accurate x-y coordinate on the map for our test locations. Detailed implementation of this function can be found in "Tools/coordinate_generation.py". The following is a screenshot of the coordinate, by moving the mouse on it, we can read the (x,y) location and manually input it to our data collection program.

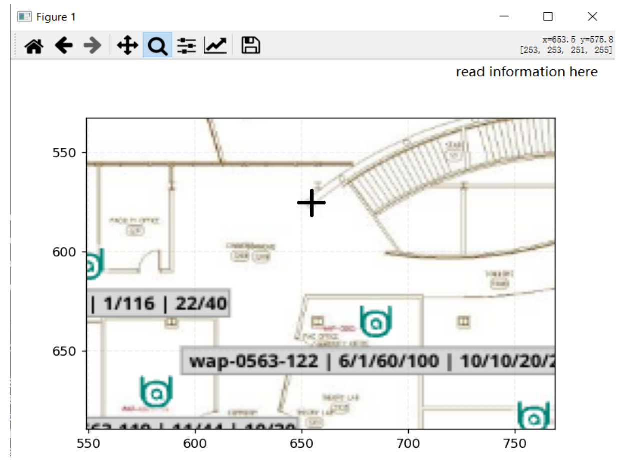

Figure 2: Coordinate details of third floor

We initially considered using GPS to gather location data. However, two factors cause this approach inefficient:

(1) Computers do not inherently support the necessary signal receiver, making it difficult to seamlessly collect data using Python.
(2) Although mobile phones are equipped with GPS receivers, the performance indoors is subpar. From our trials, most locations had a deviation of 3-5 meters.

Consequently, we choose manual marking to collect data, which can achieve meter-level precision due to the high pixel resolution of our floor plan. Worth mentioning, based on experience, positioning oneself on the map for data collection can be assisted by markers such as doors, staircases, and elevators. Load-bearing columns and room corners are good testing points as they help find corresponding coordinates while reducing interference to a certain extent.

Data Collection We obtained information on the location of all the APs and their BSSIDs in the Thomas M. Siebel Center building from the IT department. We then wrote a data collection program using the Pywifi library, which can be found in "Tools/data_collection.py". At each test location, the program searches for all the Wi-Fi access points it can receive signals from and records the Wi-Fi BSSID and its signal strength for each AP. The BSSID of the AP the device is currently connected to is recorded as well.

The test device is Latitude 3301(Dell.inc), with NIC to be Intel(R) Wireless-AC 9560 160MHz. The optimal protocol is 802.11ac: multiple antenna, 2.4-5 GHz range, Up to 1.69 Gbps. We observed Wi-Fi 6 devices can utilize 802.11ax to gain better performance. Considering the daily working routine of faculty and students, we choose the lighter one to collect data.

We ran the test at each location three times and took the average signal strength to ensure accuracy and account for any fluctuations in the signal strength. Due to time and access limits, we only performed tests on the first and third floors in the Thomas M. Siebel Center Building. We connected to eduroam on the first floor and IllinoisNet on the third floor to make a comparison of the two mainly used Wi-Fi across the campus. The raw data collected can be found in "raw_data/illinois_net_raw_data.csv" file.

Data Processing After collecting the data, we processed it to extract meaningful insights. The data processing program can be found in "Tools/data_preprocessing.py".
First, we filtered out the data of BSSIDs that the device was connecting to at each test location. Since a device may not be connecting to the AP with the strongest signal strength, the filtration ensures the data of signal strength to be the actual strength of the device connection.
Second, we extracted the test data for each individual BSSID. The aim is to visualize the signal range and strength of each AP, then analyze whether this AP is adequately utilized.

Heatmap Generation Radial basis function is used for interpolation in the heatmap generation, implemented by the Rbf function from "scipy.interpolation" library. This allowed us to visualize areas with strong and weak signal strength, which will be used to identify locations requiring improvement. The results of the heatmaps can be found under the "heatmap" folder.
To further understand the Wi-Fi performance in areas with weaker signal strength, we drew a heatmap to show the signal strength for each single AP. This helped us to understand the effective range of each AP and how devices switch between them when moving around the building.

Overall Analysis Based on our data analysis and generated heatmap, we counted the number of AP we passed and the number of AP we connected to. And then we calculate the average signal strength of each connected AP. Based on this, we further discuss the overall performance of the network in the building and try to find out the problems of AP placement.

4 RESULTS

Generally speaking, the campus network performs well in the indoor environment. Even though the building structure is quite complex and the functionality of different areas varies, the network coverage and signal strength are usually reliable. For a detailed analysis, given Siebel Center's relevance for daily routine and its functional diversity. The building is divided into two main functional areas: Education and Research. The ground floor serves as the primary area for students' daily studies, while the third floor includes many research labs and conference rooms.

4.1 Signal Strength on Ground Floor

Our analysis of the Wi-Fi signal strength data collected from the Thomas M. Siebel Center building showed that the signal strength throughout most of the building is strong. However, we did identify a few areas where the signal strength is relatively weaker.
Based on the heatmaps we generated from the collected data, we observed that the signal strength in most areas of the building ranged from -40 dBm to -70 dBm, which is considered a good signal strength. In particular, a signal strength of -55 dBm is the minimum requirement for applications that require very reliable, timely packet delivery, while a signal strength of -70 dBm is the minimum requirement for reliable packet delivery[8].

However, there were a few areas on both the first and third floors where the signal strength was weaker, ranging from -70dBm to -80dBm, indicating a weaker signal strength. In these areas, packet delivery may become unreliable and users may experience slow internet speeds[8].

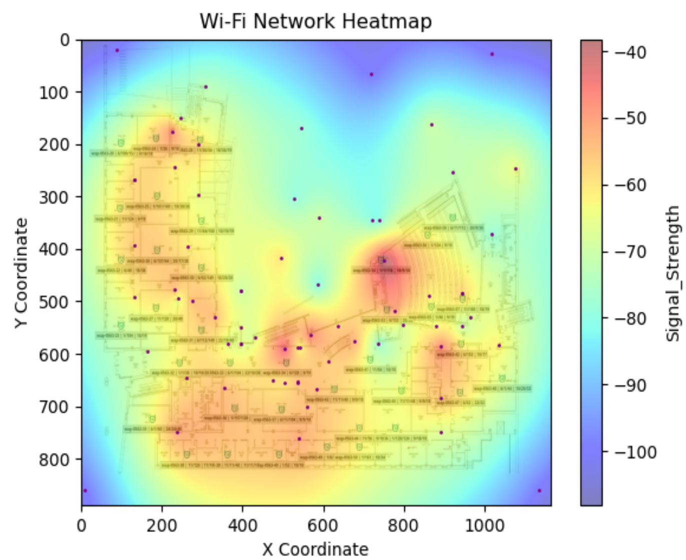

Figure 3: Wi-Fi signal strength of eduroam on Ground Floor

4.2 Signal Strength on Third Floor

Considering the research faculty have netid, they can access the faster illinoisNet. Based on observation, both the upload and download of illinoisNet are far more faster than eduroam (804 Mbps, 901 Mbps compared to 409 Mbps, 510 Mbps). However, the data transmission speed is also affected by many other factors, including the device's hardware, the network traffic, and the user's distance from the AP.
Similar to the ground floor, the signal strength on the third floor is generally reliable. Nevertheless, there are a few areas where the signal strength drops to -70 dBm to -80 dBm, indicating the possibility of slower internet speeds and unreliable packet delivery.

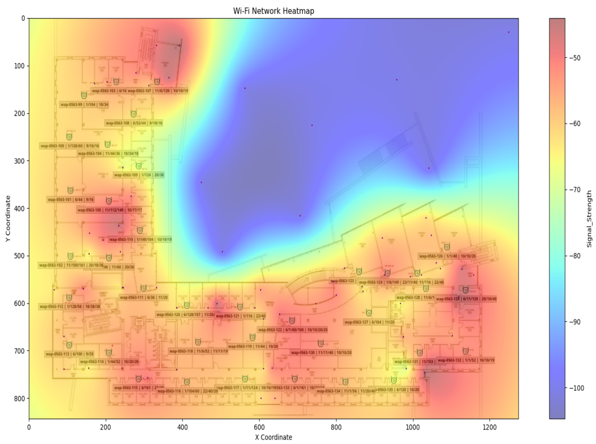

Figure 4: Wi-Fi signal strength of illinoisNet on Third Floor

4.3 Signal Strength of single AP

While most APs provide strong signals, indicative of their effective placement and functioning, a few have weaker performance.
This discrepancy could be due to various factors. Firstly, the AP placement could be sub-optimal or based on an incorrect floor plan, leading to signal obstructions or weakened coverage. Physical barriers within the building, such as walls and doors, could also impact signal propagation, reducing the effective coverage of an AP[7]. The following image shows the coverage area of this AP is not ideally circular. Rather, it occasionally undergoes multi-path propagation, which may block yet also enhance the signal.

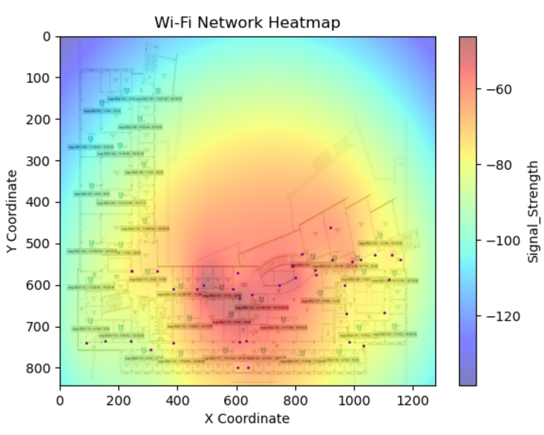

Figure 5: Wi-Fi signal strength of IllinoisNet wap-0563-122

Additionally, the number of concurrent users accessing an AP can impact its signal strength. During peak usage times, the increased load could potentially weaken the signal strength experienced by each device.
Lastly, there were instances where device connections to APs did not align with proximity expectations. For instance, the AP below performs badly. Our device would connect to a farther AP, despite a closer one with a stronger signal being available. This could be due to the internal roaming algorithm favoring factors beyond just signal strength, which will be further discussed in the next section.

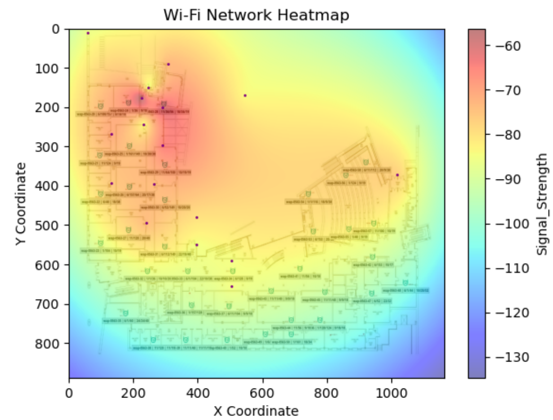

Figure 6: Wi-Fi signal strength of illinoisNet wap-0563-028

4.4 Observed AP Switching Mechanism and possible problems

Through our analysis, we observe some AP perform a weaker average for signal strength(< -60dBm). We tested the single AP performance of the weaker AP and found it performed strongly as expected. Then we step through images and find the cause of this weaker performance may be the AP switching mechanism, also known as 'roaming'. Ideally, the device would connect to the AP with the strongest signal. However, there were instances where the device remained connected to an AP with a weaker signal despite the proximity of an alternative AP with a stronger signal. This could be attributed to delays in the roaming mechanism or the specific Wi-Fi settings on the device.

Due to this reason, we find some APs are not connected to through our travel. We passed all APs in the building when we walk through, but we only connected to half of them. Specifically, we noticed that certain APs were never accessed. The issues with these underutilized APs are summarized in the table below:

We observed that some APs were never accessed in

Router	Problem
wap-0563-32	All connect to farther wap-0563-31 or wap-0563-36
wap-0563-33	All connect to farther wap-0563-31 or wap-0563-36
wap-0563-34	All connect to farther wap-0563-31 or wap-0563-36
wap-0563-34	Address is wrong, connects to wap-0563-37
wap-0563-36	Weak, -62 dBm
wap-0563-118	Weak, -60 dBm
wap-0563-42	Weak, priority connect to farther wap-0563-48

Table 1: L1 Router Problems

We found that the lower right, upper left, and lower left corners of the building did not have appropriate routing. Some nodes had signal strengths that were disproportionately high, leading to an overriding preference for these nodes. These findings highlight areas for potential improvement in the AP distribution and configuration within the building.

5 DISCUSSION

There are still much improvement space for our simple tool, and a well-defined heapmap needs more data collection.Due to limited access to certain areas within the building due to restricted access or ongoing classes, we can only test part of the Siebel Center, while current outcome still prove the functionality of our tool. The hands-on project itself is the most valuable experience.

While the Wi-Fi signal strength at a same location is stable at most times, we did find that in some tests, the signal strength varied significantly within a short time frame. For example, the signal strength at a test location close to the coffee bar on the first floor increased from -80dB to -68dB in two consecutive tests. There are several potential reasons for this variability, including:

(1) Interference from other devices: Phones, microwaves, or Bluetooth devices can generate similar frequency microwave . If there are many other devices operating in the same area, the interference will result in a weaker received signal.
(2) Changes in the physical environment: the presence of obstacles or pedestrians, can affect the strength of the Wi-Fi signal. For example, if a person moves between the device and the router during a test, variations will occur in the data.
(3) Multi-path propagation: In an indoor environment, Wi-Fi signals can bounce off walls, ceilings, and other objects, creating multiple paths for the signal to reach the receiver. This can lead to constructive and destructive interference, causing fluctuations of data.
(4) APs roaming: The Wi-Fi signal strength can also vary due to the device's ability to switch between access points. A device may switch between APs based on signal strength, congestion, or other factors. This switching can cause fluctuations in the signal strength at a given location.

It is worthwhile to notice that, since the test device only supports Wi-Fi 5, the campus network might have better performance when a terminal device can adapt 802.11ax protocol. Because Wi-Fi 6 introduces OFDMA (Orthogonal Frequency Division Multiple Access) and MU-MIMO (Multi-User Multiple Input Multiple Output) to improve performance. These technologies allow for more efficient use of the available spectrum and better performance in congested environments, which might result in perceived stronger signal strength[2].

6 ACKNOWLEDGEMENT

Our group would like to express gratitude to Prof.Deepak and UIUC Network IT team for their valuable insights and technical assistance throughout the project. The Access Point Information is extremely helpful to our research. Due to security considerations, before open source code online, we delete this information, with only the ground floor and third floor heat map outcomes.

7 CONCLUSION

In a nutshell, this mini project is a valuable practice for our study, in which we gained many inspiration and a deeper understanding of our course. The data-pipeline construction and precise measurement procedure are fundamental and helpful experiences for future research. In a single building scenario, our work highlights the importance of in-depth, granular analysis in understanding and optimizing wireless network performance. The pipeline for data collection, cleaning, and visualization, as well as the process for precise measurement, will serve as a robust foundation for future research in this area. We believe that this project will inspire further exploration and innovation in wireless network analysis, ultimately leading to more efficient and reliable network systems.

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