An Optimization of Jingyao Residential Hall Router's Location

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1 Introduction

1.1 Background

In the context of modern society, the Internet has become an integral part of our daily lives. With the rapid development of information technology, internet access has become an indispensable part of our daily lives. In the era of digitalization, access to high-speed internet is not only a requirement for personal entertainment and work but also a fundamental need for education. Universities and college campuses are not an exception to this trend. To satisfy the increasing internet connectivity demands, educational institutions need to optimize their internet infrastructure, especially in their residence halls, where students spend most of their time. Therefore, having a fast and reliable Internet connection is crucial. Jingao Residential Hall houses more than 500 students, and each student has a laptop, tablet or smartphone, which is used to access the internet. The hall currently uses a wireless network, but the internet connection is often slow and unstable, which affects the students' academic and personal activities. In this regard, it is critical to optimize the router's location to ensure that everyone enjoys a stable and fast connection.

1.2 Our focus

Based on the background knowledge stated before, we would like to develop an optimization model that can determine the placement of Wi-Fi routers in Jingyao Residential Hall, the student residence hall at NYU Shanghai. Our goal is to determine the router's optimal location, which will provide a better Internet experience for all residents in JingYao

Residential Hall. This paper will discuss the methodology used to determine the optimal location, the results of the analysis, and the implications for future research.

1.3 Problem Description

To illustrate our interpretation and modeling of this problem, the main issue is the strength of the Wi-Fi signal, so the following parts explain the factors that affect the strength of the Wi-Fi signal, which relates to c_{ij} in our model.

1.3.1 Wi-Fi Signal strength assessment

The strength of a Wi-Fi signal is usually measured in decibels-milliwatts (dBm), which is a unit of power that represents the signal strength relative to 1 milliwatt. In general, the higher the dBm value, the stronger the Wi-Fi signal.

Several factors need to be considered to evaluate the strength of a Wi-Fi signal. These factors include the distance between the device and the wireless access point, the number of walls and other obstructions between them, the type of material used for the walls, the presence of other Wi-Fi networks or electronic devices operating on the same frequency band, and the type of antennas used by the device and access point.

In addition, interference from other sources, such as the presence of microwave ovens, Bluetooth devices, and cordless phones, can also affect the strength of Wi-Fi signals. These factors can cause signal attenuation, interference or reflection, resulting in weaker signal strength and slower data transmission.

1.3.2 Network Range and Distance between Devices

The range of a Wi-Fi network and the distance between devices can have a significant impact on the strength of Wi-Fi signals. A Wi-Fi signal is strongest when devices are close to the router and weakest when devices are far away from the router or out of range. The range of a Wi-Fi network is determined by the power of the router's antenna and the frequency of the signal. The higher the frequency, the shorter the range, and the lower the frequency, the longer the range. Wi-Fi routers typically use either the 2.4GHz or 5GHz frequency bands, with 2.4GHz providing longer ranges but lower speeds and 5GHz providing shorter ranges but higher speeds. And the frequency band of the Wi-Fi in Jingyao Residential Hall is 5GHz, which means a high speed and a short range.

1.3.3 Physical Obstructions

Physical obstructions are also another primary factor that can affect the strength and quality of Wi-Fi signals. The signal strength can be weakened or blocked entirely if the signal has to travel through walls, doors, furniture, and other objects. The farther the signal has to travel, the more it will weaken. Obstructions made of thicker and denser materials can absorb and reflect the signal more, leading to weaker signal strength. Metal objects are especially problematic for Wi-Fi signals because they can reflect and interfere with the signal. Materials such as concrete and metal can block or weaken signals more than other materials like drywall, wood, and glass. A study by NetSpot found that concrete walls can reduce Wi-Fi signal strength by up to 90%, while drywall only reduces signal strength by 20-40%. This shows that the type of material an obstruction is made of can have a significant impact on Wi-Fi signal strength.

1.3.4 Wireless Network Interference

Another factor that can affect Wi-Fi signal strength is wireless network interference. This happens when other electronic devices or Wi-Fi networks operating on the same frequency band interfere with the Wi-Fi signal. This interference may result in packet loss, reduced signal strength, and slower data transmission.

The most common sources of wireless network interference include other Wi-Fi networks, Bluetooth devices, and microwave ovens. These devices operate on the same frequency band as Wi-Fi, which can lead to interference and reduced signal strength. In our quarters, these interferences are only present in the number of electronic devices. After our tests, when more electronic devices are used in the same room, then the network becomes slower.

2 Model Formulation

2.1 Model Explanation

2.1.1 Decision variable

We denote $I = \{1,..., n\}$ as the demand location, which refers to the location where the electronic device is in this problem. And then we denote $x_i \in \{0, 1\},\ i \in I$ to be the binary variable, which equals 1 if a router is placed at the site i and 0 otherwise.

2.1.2 Objective Function

We denote $J = \{1,..., m\}$ as the supply location, which refers to the location where the routers are placed in this problem. And $w_i,\ i \in I$, is defined as the demanded number of site i, which reflects the frequency of using electronic devices in this place. And we use the number of devices in the area i to represent w_i. For example, if in site 1, it has 5 electronic devices, then $w_i = 5$. Then $c_{ij},\ i \in I,\ j \in J$, is defined as the signal strength of Wi-Fi, at location j for device i. In real life, Wi-Fi strength can be affected by many things, such as the way the furniture is placed around it, the blocking of walls and doors, etc. And more information will be explained in 2.4. So we will not directly calculate the value of c_{ij} based on the ideal value but will take into account the impact factor on the loss of Wi-Fi strength. Next we denote $y_{ij},\ i \in I,\ j \in J$, as a binary variable to determine whether the strength of the router at j can cover device i. $y_{ij},\ i \in I,\ j \in J$ equals to 1 if the strength of the router at j can cover device i and 0 otherwise.

Let denote z as the total Wi-Fi signal strength, i.e..$z = \sum_{i\in I}\sum_{j\in J} w_i c_{ij} y_{ij}$.

2.2 Maximum Signal Model

We refer to the generalized maximum coverage model proposed by Berman and others in 2002[1] . This model requires that all demand points can be covered to different degrees, and the goal is to maximize the weighted sum of the total covered nodes. We improve their model to fit our router optimization. Our objective is to maximize the total Wi-Fi signal strength, so the problem can be formulated as:

$$max \sum_{i\in I}\sum_{j\in J} w_i c_{ij} y_{ij}$$

$$s.t. \quad \sum_{j\in J} x_j = N \qquad (1)$$

$$\sum_{j\in J} y_{ij} = 1, \quad \forall i \in I \qquad (2)$$

$$y_{ij} \le x_j, \quad \forall i \in I, j \in J \qquad (3)$$

$$x_j \in \{0, 1\}, \quad \forall j \in J \qquad (4)$$

$$y_{ij} \in \{0, 1\}, \quad \forall i \in I, j \in J \qquad (5)$$

2.3 Constraints of Maximum Signal Model

We have five constraints in total. And we will explain them in this part. The first one ensures that the total number of Wi-Fi routers is equal to the constant N. The second one ensures that every electronic device is connected and only connects to one Wi-Fi router. And the third one ensures that only the situation that places the router, router can cover electronic devices. For example, when site j has a router, then y_{ij} can be equal to 0 or 1, otherwise y_{ij} can only be equal to 0. The fourth and the fifth constraints ensure that the x_j and y_{ij} are binary variables.

2.4 Parameter of Maximum Signal Model (c_{ij})

As explained in the objective function part, c_{ij}, $i \in I,\ j \in J$ is defined as the signal strength of Wi-Fi, at location j for device i. It has a strong correlation with the distance between devices, physical obstructions such as walls, wireless network interface and so on. To simplify the problem, we assume that the only factor that needs to be considered in our model is the distance between the Wi-Fi router and the electronic devices. And the parameter c_{ij} is formulated as:

$$c_{ij} = 1 - P_L$$

P_L represents the path loss, i.e., the attenuation and loss of the signal during transmission, which can be evaluated by the Log Distance Path Loss Model [2]:

$$P_L = 0.01 \times (U_L + 10 \times n \times log(d))$$

U_L : power loss (dB) at 1m distance (30dB)

n : path loss coefficient factor (0.35)

d : distance between the electronic device and the Wi-Fi router

3 Data Collection

3.1 Floor Plans for Jingyao Residential Hall

Figure 1 is the floor plan of Jingyao Residential Hall, which is the subject of our study. Taking into account the planning of related facilities, etc. Since the entire floor plan is nearly perfectly symmetrical, we only need to consider half of it, while the other half is the same situation. We divided half of the floor plan into squares and labeled them sequentially from top to bottom, left to right, which is shown in Figure 2. The number 1 to 30 represents the place where we can put the Wi-Fi router and the place where we have the electronic devices. We suppose that we have 5 Wi-Fi routers by considering the cost of the routers as well as the power. And the triangle symbols in Figure 3 show the places where we have the electric devices.

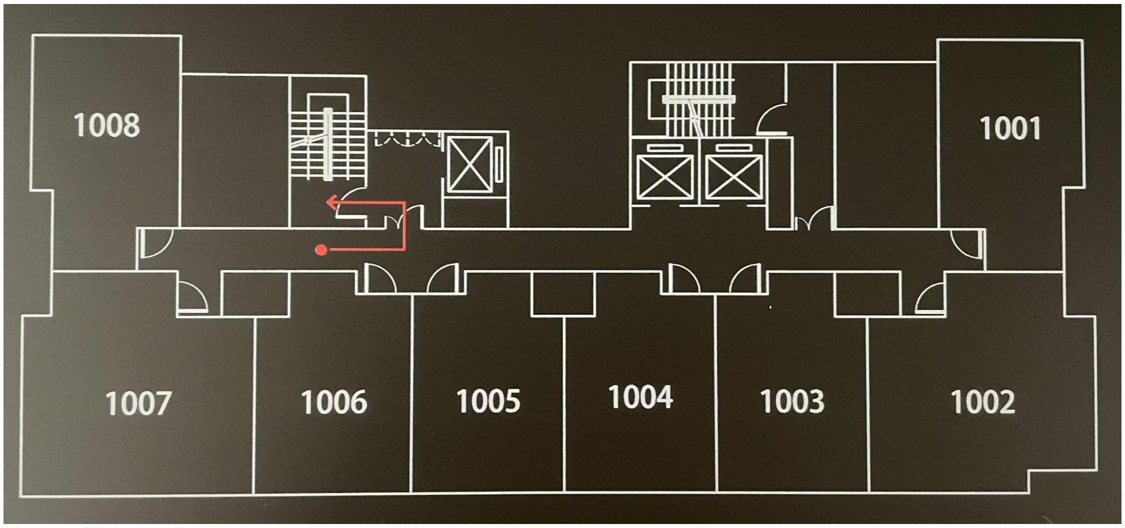

Figure 1: Original Floor Plan of 10th-floor

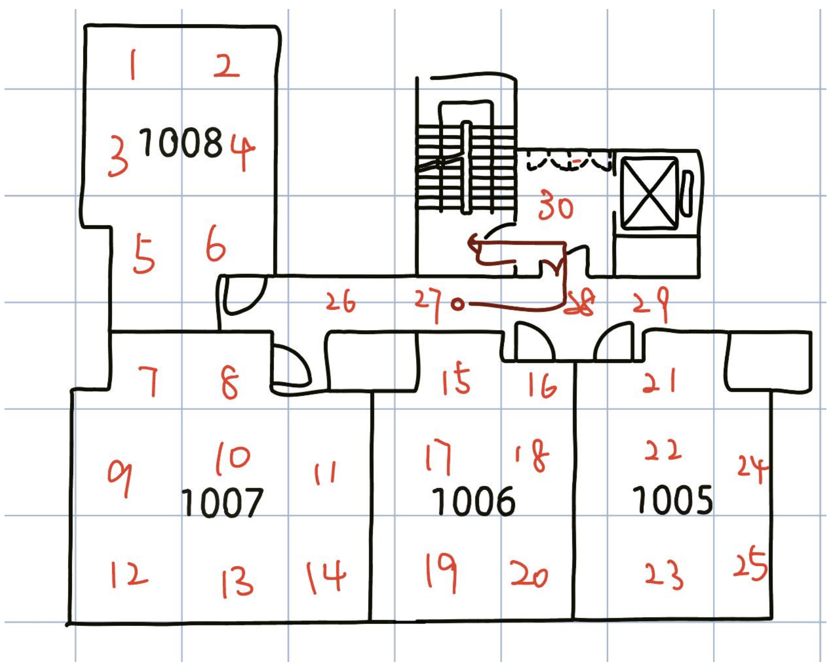

Figure 2: Left side grid diagram

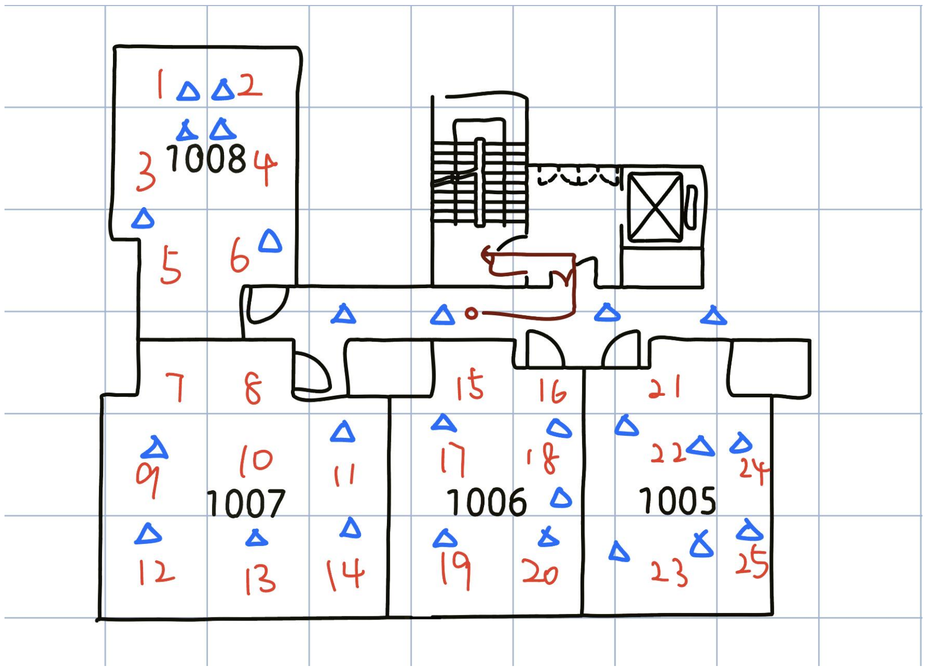

Figure 3: Grid diagrams with the location of electrical devices

3.2 Data Processing

Once we have the data collected, we start processing the data. As c_{ij} only correlates with the distance between electronic devices and the Wi-Fi router, the loss is very small because of the limited space of our dorm, shown in Figure 4. Therefore, the difference in the value of c_{ij} is negligible, and we can ignore the effect of the parameter c_{ij} and simplify our problem.

```
[1]  import math

[23] list1 = [100,140.14,200,220.36,300,310.6,400]
     list2 = []

[24] def f(x):
       return 1-0.01*(30+10*0.35*(math.log(x,10)))

[25] for i in range(len(list1)):
       list2.append(f(list1[i]))

     list2

[0.63,
 0.6248703260394854,
 0.6194639501517607,
 0.6179903532704552,
 0.6133007560848118,
 0.612772949201261,
 0.6089279003035213]
```

Figure 4: Python code for c_{ij}

So we suppose c_{ij} to be 1. In our previous model, y_{ij} is influenced by c_{ij}. Then, y_{ij} can be simplified to be y_j . And for each y_j, we considered it to be the weight value of the x_j around it based on our collected data. And this range we consider a square grid of 3×3 around the center of y_j . We tested the signal values at different locations and recorded them as 1 for the grids with signals. Our weighting strategy is to simplify the impact of c_{ij} by averaging the grids with 1 around each one.

4 Results and Discussion

We solve the problem with Excel and get the optimal solution which is in Figure 5. Specifically, our data showed that the router positioning in all four rooms tended to be slightly biased towards the center of the room but closer to the corridor side.

This finding is consistent with our intuition that a centrally located router can provide better coverage for the entire room while positioning it closer to the corridor ensures that the signal can also extend to adjacent rooms.

Additionally, we observed that the signal strength was negatively affected by obstacles such as walls and doors. In particular, our data revealed that rooms with more walls and doors tended to have weaker signal strength compared to those with fewer obstacles. This highlights the importance of considering the physical layout of the building when positioning the router. In some cases, it may be necessary to experiment with different router positions and antenna orientations in order to achieve optimal signal coverage.

Overall, our findings suggest that a centrally located router and close to the hallway provides better coverage for the entire floor. However, the layout of individual rooms, furniture arrangements, and obstructions such as walls and doors may affect the optimal placement of routers. By taking these factors into account, residence hall managers can ensure that the Wi-Fi signal is strong and reliable throughout the building.

wi	yi	xj	z
2	0.25	0	0.5
3	0.25	0	0.75
3	0.2	0	0.6
2	0.16666667	1	0.33333333
1	0.16666667	0	0.16666667
3	0.16666667	0	0.5
3	0.16666667	0	0.5
1	0.11111111	0	0.11111111
2	0.33333333	0	0.66666667
2	0.25	1	0.5
3	0.25	0	0.75
3	0.5	0	1.5
2	0.33333333	1	0.66666667
3	0.33333333	0	1
1	0.125	0	0.125
1	0.22222222	0	0.22222222
3	0.125	0	0.375
3	0.22222222	1	0.66666667
2	0.16666667	0	0.33333333
2	0.33333333	0	0.66666667
1	0.28571429	0	0.28571429
2	0.25	1	0.5
3	0.33333333	0	1
2	0.2	0	0.4
2	0.25	0	0.5
1	0	0	0
1	0	0	0
1	0	0	0
1	0	0	0
1	0	0	0
		5	13.6190476

Figure 5: the Optimization of Wifi-Router Location

5 Future Outlook

While our model has simplified the relationship between Wi-Fi signal strength and distance, it is important to note that this situation is more complex in the real world, and many other factors can affect Wi-Fi signal strength. For example, physical obstructions, such as walls and floors, can significantly reduce signal strength, as well as interference from other wireless devices and environmental factors like weather conditions. As such, future research could focus on developing more sophisticated models that take into account these additional factors, to better understand and predict Wi-Fi signal performance in real-world scenarios.

Furthermore, as the demand for wireless connectivity continues to grow, it will be important to develop new technologies and protocols that can improve Wi-Fi signal strength and reliability. This could involve innovations in antenna design, signal processing, and network optimization, as well as the use of new frequencies and bands to reduce interference and improve signal quality. Additionally, the development of new IoT devices and applications will require even more robust and reliable wireless networks, making it important to continue researching and developing new solutions to meet these evolving needs.

References

[1] Berman, O. and Krass, D. (2002) 'The generalized maximal covering location problem', *Computers and Operations Research*, 29(6), pp. 563–581. doi:10.1016/S0305-0548(01)00079-X.

[2] Ali, A.H. *et al.* (2010) 'Investigation of indoor WIFI radio signal propagation', *2010 IEEE Symposium on Industrial Electronics and Applications (ISIEA), Industrial Electronics & Applications (ISIEA), 2010 IEEE Symposium on*, pp. 117–119. doi:10.1109/ISIEA.2010.5679486.