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Case Study: Free Space Path Loss for Mobile Network and WLAN

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ABSTRACT

Wireless communication systems transmit and receive information through free space. Thus, there are other factors to consider when designing a wireless communication system. One of those factors is Free space Path Loss (FPSL), which refers to the loss of signal strength in the propagation of the signal in free space. In this study, the effects of obstruction and distance on the FSPL of the transmission in mobile networks and Wireless Local Area Networks (WLAN) will be measured. The measured results show that the obstructions have a higher impact on the received signal compared to the distance. In the mobile network setting, the open area has an FPSL of 111 dB, whereas the obstructed office area has a significantly higher FSPL of 158 dB. Furthermore, in the WLAN setting, the FSPL of an obstructed area is 19 dB higher than the line-of-sight propagation. Thus, the layout of the area to implement a wireless communication system must be thoroughly analyzed for obstructions and distance to provide optimal wireless communication service to customers.

Keywords: Free-space path loss, Mobile Networks, Signal Strength, WLAN

1. INTRODUCTION

The main objective of a wireless communications system is to transmit and receive information, mainly through free space. However, there is a multitude of factors that will hinder the receiver from receiving said information. One of those factors is free-space path loss (FSPL), which refers to the loss of signal strength in the propagation of the signal itself. The FSPL has to be identified within a system so that smart planning and designing of wireless local area networks (WLAN) networks can be done for closed environments such as homes or offices [1]. This is not just limited to closed environments. However, the propagation of wireless networks in a telecommunication cell also has to take path loss into account when designing to provide an optimal experience for their user base. Thus, it can be said that to deploy the new communication systems most cost-effectively and efficiently, it is beneficial to understand how the received signal strength performs in different environments [2].

This case study aims to study the effects of obstruction and distance on the FSPL in Mobile Networks and WLAN. Thus, the FSPL will be measured in two different settings. One, in an open space with a set distance from the mobile network cell tower, and two, in an indoor setting with a set distance from the WLAN router. The two methods are selected because the two settings closely replicate real-world settings, therefore, can retrieve a result closer to actual applications.

1.1 Path Loss

These losses are mainly due to the general properties of electromagnetic wave propagation of reflection, diffraction, and scattering [3]. When a radio wave encounters another medium with different electrical properties, the wave is partly reflected and absorbed. Furthermore, the

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reflection coefficient is a complex function that generally depends on the wave's angle of incidence, frequency, and transmission polarization. The diffraction property generally allows the signal to propagate behind obstructions. However, the transmission speed will be slowed down. The scattering property occurs when the transmitted wave encounters small objects smaller than the wavelength of the signal. Then, the energy is spread out in all or at least many directions. It could be used as an advantage in RADAR uses [4]. However, the scattered wave will cause the wave to reach the receiver from different directions, with different path lengths, attenuation, and delays resulting in an attenuated signal due to its propagation through multiple paths.

Since wireless communication transmits by the air, in free space, the air changes would affect the transmission link. Thus, the weather would be a cause of path loss too. For example, during the rain, the water's properties would affect the wave transmitted. Furthermore, the transmission of other waves of identical frequencies would cause interference. The transmission of waves from adjacent base stations would disturb the communication between other base stations and mobile stations using the same carrier if the frequency is not correctly divided, thus, causing crosstalk [5].

There are a few methods to reduce the FSPL within the system: decreasing the distance between the transmitter and receiver, changing the frequency band into a lower one, and minimizing the obstructions between the transmitter and receiver. However, in some cases, even after using all the methods above to reduce the FSPL, it could not be mitigated due to the general properties of electromagnetic wave transmission. Therefore, the system itself could be upgraded, such as using MIMO antennas [6], employing multi-hop mobile Adhoc networks [7], use of metamaterials [8], or even using machine learning to improve the performance of the system [9].

2. MODEL AND DATA

2.1 Free-Space Path Loss (FSPL)

In this case study, the following formula will be used for calculating the path loss between the transmitter and receiver in both measurements. The FSPL formula derives from the Friis transmission formula [10]. The formula can be defined using either wavelength or frequency of the transmitted signal shown below:

$$\mathrm{FSPL} = \frac{P_t}{P_r} = \left(\frac{4\pi R}{\lambda}\right)^2 = \left(\frac{4\pi R f}{c}\right)^2 \tag{1}$$

Where,
FSPL = Free space path loss,
R = distance from the transmitter to the receiver (m),
λ = signal wavelength (m),
f = signal frequency (Hz),
c = speed of light (m/s).

Then the FSPL can be used to find the transmitted power or received power in dB:

$$\mathrm{FSPL} = P_t - P_{r\ (\text{in dB})} \tag{2}$$

Where,
P_t = Power transmitted (dB),

P_r = Power received (dB),
FSPL = Free-Space Path Loss (dB).

2.2 Mobile Network Transmitted Power

Due to the lack of access to measure the transmitted power directly at the base station, the transmitted power has to be assumed according to the national standard. Therefore, according to the Malaysian Technical Standards Forum Bhd (MTSFB), the typical base station antenna transmits at 41dBm, which is approved by the national communications governing body, the Malaysian Communications and Multimedia Commission (MCMC) [11]. However, the accuracy of the transmitted power is hardly an issue because the main objective is to find the relationship between the free-space path loss and distance.

2.3 Mobile Network Transmitted Power

The transmitted power of the WLAN signal is taken by placing the mobile device as close as possible to the WLAN transmitter without any obstructions. The reading will be assumed as the transmitted power of the WLAN transmitter itself. In this case study, the reading obtained for the transmitted power of this case study is -22 dBm at the transmitting frequency of 2.417 GHz, as shown in Figure 1 below.

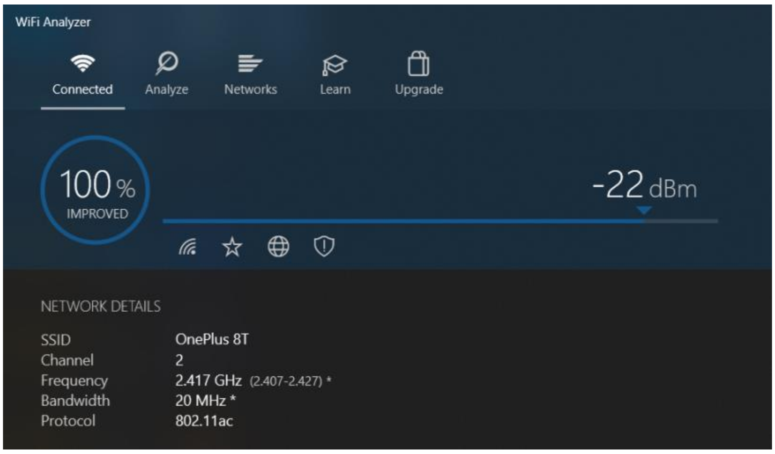

Figure 1: WLAN Transmitted Power.

3. METHODOLOGY

For this case study, there are two types of transmission in which the Free Space Path Loss is to be measured. The first is Mobile Network, and the second is WLAN. The measurement methods for both types are different and will be further discussed in the sections below.

3.1 Mobile Network Measurement

In this experiment, the effect between the distance and FSPL is measured. Furthermore, the FSPL is measured in three different types of locations: open areas, office buildings, and living quarters. This is to measure if obstructions constitute a significant factor to the FSPL other than distance.

Before measuring the strength of the mobile network signal, a mobile application (App) is installed on the mobile device to test. The App is called Network Cell Info Lite & WiFi downloaded from the Google Play App Store (Figure 2). It is developed by m2catalyst, a big data company that measures and analyses mobile user experience across every mobile operator worldwide. It is used to monitor mobile and WiFi signals; thus, the readings will be obtained from the App itself. Multiple readings of the exact location will be taken from each point, and the average of all readings in the same location will be recorded for consistency.

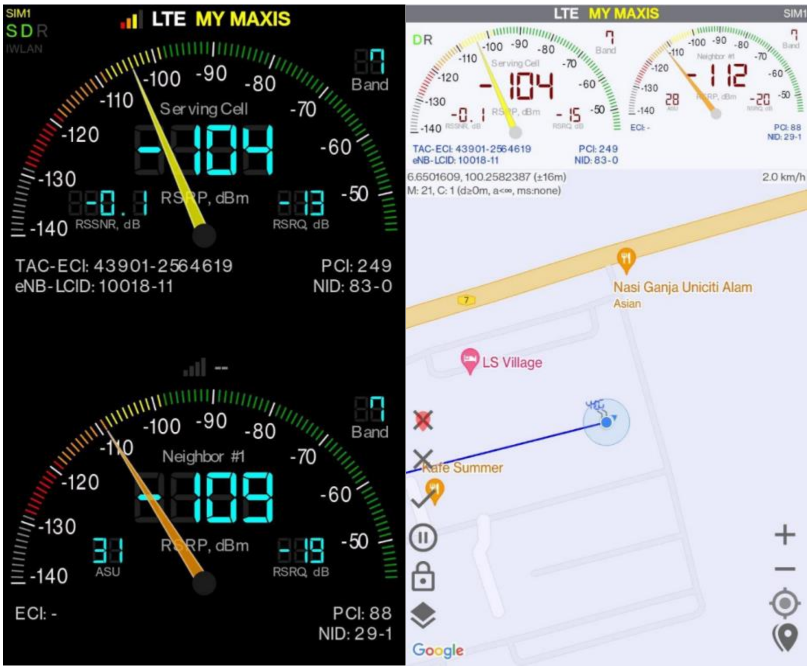

Figure 2: Details of Mobile App used.

First, the cell tower location is located using the App, then the readings of the received power level will be recorded. This process is then repeated by facing different directions but at set distances from the previous recordings. Each direction will have various obstructions between the cell tower itself; thus, the free space path loss would vary between them. Figure 3 shows the cell tower location and the marked locations where the readings will be recorded.

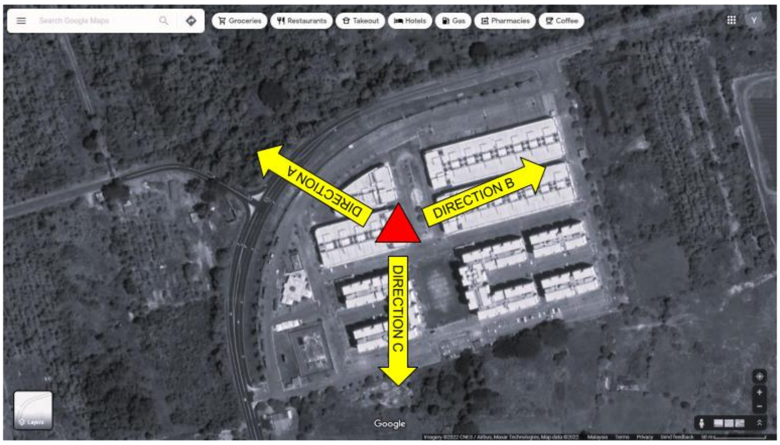

Figure 3: Mobile Connection Measurement.

In Figure 3, the red triangle shows the cell tower's location, while the yellow arrows represent the direction where the measurements will be taken. All three different directions have different characteristics, where direction A is towards an open area close by to a road with little to no obstructions, direction B is towards an office building with various electrical equipment, and direction C is towards a densely packed hostel of students. The readings will be taken at different distances in the direction of the selected locations to measure the relationship between distance away from the transmitter and path loss.

3.2 WLAN Measurement

For this experiment, the same parameters are measured as in the previous experiment but a WLAN setting. However, the experiment is conducted twice to further experiment with the effects of distance in an obstructed area and FSPL. The first measurements are taken where the transmitter and receiver are in the line of sight at different distances. Then the same values are retaken in a living quarter setting (hostel) to see the effects of obstructions on the FSPL.

As with the Mobile Network Measurement, an App is installed on the mobile device to test. The App is WiFi Analyzer, downloaded from the Microsoft Store on the computer (Figure 4). This App can measure the strength of the WLAN signal and the frequency in which both will be measured and recorded.

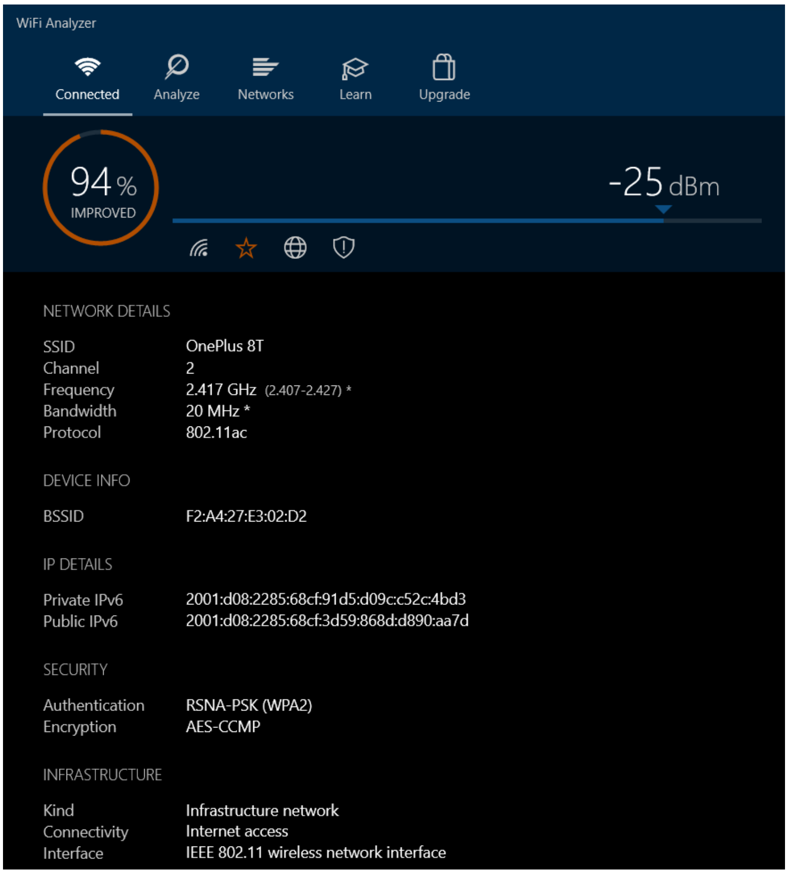

Figure 4: WIFI Analyzer App Interface.

The experiment will be conducted twice, with the same distances, however, in different situations. The first part of the experiment will be done in a line-of-sight (LOS) setting to gauge the power received. Then the experiment will be done again in a home setting, and the readings will be obtained from different distances from the WLAN router in different rooms of a hostel shown in Figure 5. The displacement between the transmitter and receiver will be the same as the LOS setting.

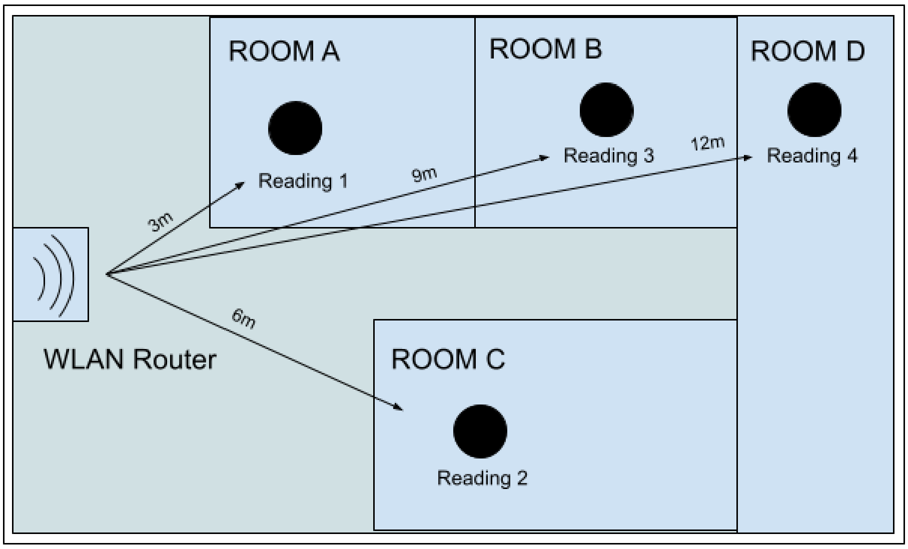

Figure 5: Indoor WLAN Measurement Setup.

4. RESULTS AND DISCUSSION

4.1 Mobile Connection

The measured signal strength for the mobile connection (as shown in 3.1) in directions A, B, and C from set distances are tabulated below in terms of distance and signal power received, P_r in dBm (Table 1 and Figure 6). The FSPL is then calculated using the formula (2) in section 2.1.

Table 1: Signal power received, P_r, and FSPL of Mobile Connection.

Distance (m)	A (Open Area)		B (Office)		C (Living Quarters)	
	P_r (dBm)	FSPL (dB)	P_r (dBm)	FSPL (dB)	P_r (dBm)	FSPL (dB)
50	-83	124	-90	131	-84	125
100	-78	119	-103	144	-95	136
150	-86	127	-104	145	-90	131
200	-86	127	-109	150	-93	134
250	-70	111	-117	158	-93	134

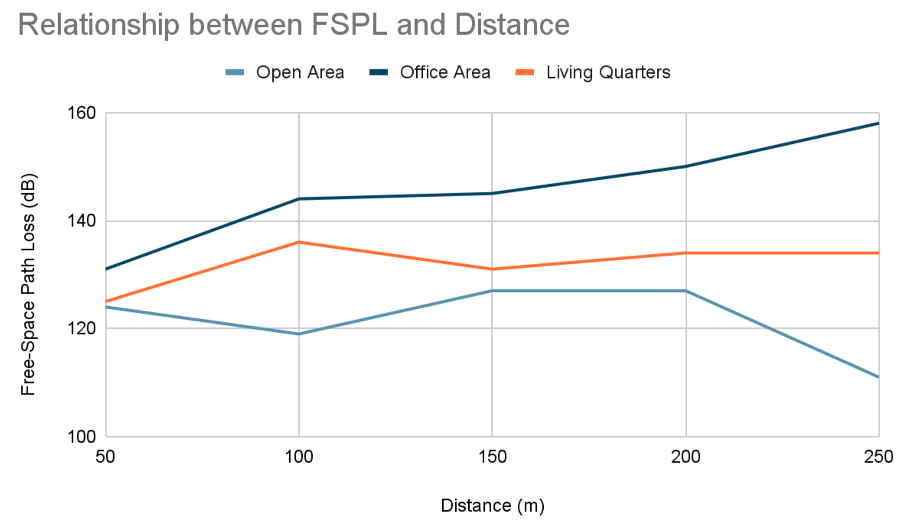

Figure 6: Graph of Relationship between FSPL vs. Distance for Mobile Connection.

The FSPL in the open area is the lowest, while the office area has the highest FSPL. The pattern between the FSPL and the distance is as expected in the office area, while it is not clear for the open area and the living quarters. This could be due to the fact that the distance selected for this case study is not far enough and is well within the range of the base station with little to no obstructions, especially for the open area where at 250 meters, it is a wide-open space, thus having a minor loss. Furthermore, this can explain the FPSL is highest in the office area due to many obstructions, such as walls, dividers, and maybe other electronic devices emitting electromagnetic waves disrupting the signal received from the base station itself. The effects of obstructions will be further investigated in the next section, WLAN.

4.2 WLAN

The signal power received on the mobile device is recorded at different distances in two different settings, the first being LOS propagation and the second being in a hostel room setting, as shown in Figure 5. The data obtained is then tabulated below (Table 2 and Figure 7).

Table 2: Signal power received, P_r and FSPL of WLAN.

Distance (m)	**LOS Propagation**		**Hostel Setting**	
	P_r (dBm)	**FSPL (dB)**	**P_r (dBm)**	**FSPL (dB)**
3	-36	14	-47	25
6	-45	23	-51	29
9	-46	24	-64	42
12	-48	26	-67	45

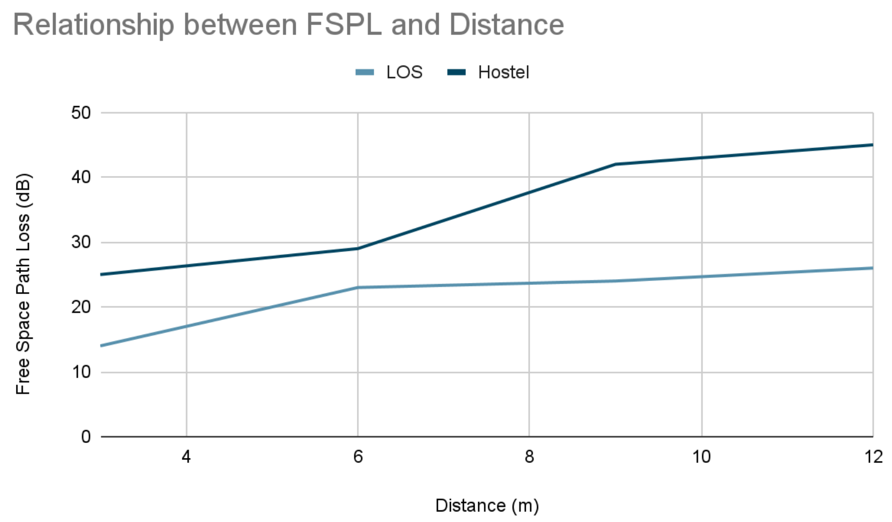

Figure 7: Graph of Relationship between FSPL and Distance for WLAN.

The LOS propagation has a lower FSPL value compared to the hostel setting, with multiple obstructions in the path of propagation even on the same transmitted frequency. Since the first measurement was taken at 3 meters, the FSPL recorded for the hostel setting is higher than the LOS setting by 11dB, and it peaks at a difference of 19dB at the last measurement taken (12 meters). Furthermore, the FSPL of both settings increases steadily as the distance increases after 6 meters. The sharp rise for the hostel setting could be due to the addition of obstructions between the router and the mobile device.

5. CONCLUSION

In this study, it can be concluded that apart from a distance, obstructions within a transmission network will also cause FSPL. The highly obstructed office area has an FSPL of 158dB, whereas an open area at the same distance away from the transmitter has a significantly lower FSPL of 111dB. This relationship is also evident in the WLAN measurement, where the FSPL is 19dB higher in an obstructed setting compared to LOS propagation. Thus, when designing a WLAN network, the area's layout must be analyzed first so that the obstructions between the transmitter and receivers are considered to obtain optimal wireless communications experience for users in the area. Generally, the lesser the obstructions are within the system, the better the signal received. The distance between the transmitter and receiver is an important factor also. However, the distance would have minimal impact on received signal power at the receiving devices within the transmitter range.

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