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Predictive Wireless Received Signal Strength Using Friis Transmission Technique

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***Abstract*—A good WLAN performance is crucial in determining the quality of experience (QoE) among the campus community. Proper WLAN planning and design should be done beforehand to ensure good WLAN performance. Various studies have discussed different methods of conducting WLAN planning to predict WLAN's best performance, including using artificial intelligence and mathematical approaches. One of the processes involved in performing WLAN planning is measuring performance parameters. Signal strength is one of the vital parameters to be measured in determining the excellent performance of WLAN in a particular area. When deploying a WLAN design in two different environments, the signal strength outcomes can differ due to various factors, including obstacles and path loss propagation issues within the deployment area. Higher Learning Institutions (HLIs) present a unique challenge as their building designs vary to accommodate student needs. As a result, the selection of materials used will also be different, affecting the WLAN performance. A detailed study should investigate the effect of path loss propagation and the type of obstacle that affects WLAN performance in HLI. Thus, this study focuses on predicting received signal strength using Friis Transmission and studying the effect of path loss propagation on WLAN performance. The simulated model significantly affects signal strength when the signal passes through different types of building material (non-LOS) and line-of-sight (NLOS), where concrete walls substantially affect the received signal strength between transmitters. The proposed model can assist network planners in designing robust WLAN infrastructure by improving signal strength, particularly in the HLI WLAN environment.**

***Keywords*— WLAN planning; Friis transmission; path loss; received signal strength.**

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I. INTRODUCTION

Education is a crucial sector in determining the great future of a country and nation. In Malaysia, the education sector has kept growing, becoming more decisive and increasing in global recognition. To retain the recognition, the Ministry of Higher Education has introduced the Malaysia Education Blueprint 2015–2025 for Higher Education to globalize online learning. Online learning can be defined as the practice of receiving instruction electronically via a variety of multimedia and Internet-based platforms and tools. Concerning online learning, the methods of pedagogy also need to be improved, and more sophisticated teaching tools should be used to deliver teaching and learning activities efficiently [1]. In the new era, learning sessions can still be enjoyed anytime and place if connected to the Internet. Maheswari [2], in their study, which aimed to understand the factors that impact students' attention during online learning, has found that ICT infrastructure, Internet speed, and Internet access contribute to Perceived Enjoyment (PE) among public and private university students in Vietnam. More research highlights the importance of good ICT infrastructure that can support good implementation of teaching and learning especially in higher learning institutions [3]. The new teaching and learning pedagogy requires fast, reliable, and flexible connections in accessing the learning content. The limitations of wired networks, such as lack of mobility, high installation cost, difficulty to install, and limited devices to access the network, have caused campus communities to change to the communication medium, wireless local area network (WLAN) technology [4].

A. *Wireless Area Network (WLAN)*

A WLAN, also known as Wi-Fi, is a technology to connect two or more devices using radio frequency as the communication medium. Using this technology, users have more flexibility to connect to the Internet using any Wi-Fi-supported device, which can also be accessed from anywhere and everywhere as long as they are within network coverage. The flexibility in accessing the network has improved many things, such as increased productivity, reduced implementation cost, shorter processing time, and many more. Cisco, in its annual Internet report, predicts in the year 2023, there will be a significant increment in network connectivity, with 71% coming from mobile connectivity [5]. The WLAN applications are used widely in various sectors such as education, tourism, hospitality, healthcare, warehouses, retail, and many more [6]. The benefits offered by WLAN technology, such as low cost, mobility, scalability, ease of use, and flexibility, have led WLAN to be widely deployed in most buildings, including HLIs. Two previous studies [7], [8] have emphasized the importance of good network infrastructure in enhancing campus user's learning experience. From an education perspective, WLAN has helped teaching and learning activities become more practical more flexible and even improved the quality of experience (QoE) among students and lecturers, especially in HLI [9].

However, Rashid et al. [10] has reported that the WLAN performance at HLI is not as expected. Issues such as lack of signal quality, low signal coverage, as well as slow network speed have caused frustration among the campus community, especially students [10], [11]. Many factors can cause those issues to happen. One of the factors was the WLAN design itself [12]. Proper WLAN planning should be conducted before real network deployment to have a good WLAN design. Good WLAN planning and design are necessary to enhance WLAN quality and satisfy customers' needs for network deployment [13]. Many processes are involved in conducting WLAN planning, including WLAN site surveys. Rawi et al. [14] in their study, which was conducted among all Malaysian public HLI, found that a physical site survey had become the most common method used before WLAN deployment. However, a physical site survey consumes more time and requires a highly expert to gather accurate results. WLAN physical site survey focuses more on signal strength and data rate as the factors to determine the number of needed WLAN devices and the placement of the devices [15], [16]. The suggestions for the required devices are commonly made based on previously conducted survey experiences. There can be significant differences between the initial planned and actual network implementation if elements like user density, obstacle types, frequency, application usage, capacity utilization, and network latency are ignored [17].

B. *WLAN Planning approaches*

According to Zvanovec et al. [18], who evaluated different techniques for conducting WLAN surveys; planning based on propagation modeling is far superior, especially when developing extensive WLAN networks. Several WLAN performance parameters must be measured to ensure a good WLAN infrastructure can be provided throughout the campus area. Recent studies discuss different approaches used to perform WLAN planning: artificial intelligence and mathematical approaches. Studies have suggested signal strength, coverage, location of AP placement, transmission power, speed, latency as well and throughput are among the parameters that should be highlighted as the preliminary input of network planning [15], [19]–[21].

Most artificial intelligence approaches focus on optimizing the WLAN performance by predicting the best location of AP placement and channel assignment [15], [20], [22]. The transmission power and placement of each access point were optimized using a hybrid swarm intelligent optimization algorithm termed PSO-Lévy-DFOA in another study by Liu et al. [19], providing efficient coverage while reducing interference.

On the other hand, authors who use mathematical approaches are more focused on measuring performance, which is later used to improve network performance in their organizations. Skendzic et al. [23] used third-party software to measure the highest WLAN resource utilization. As a result, additional new devices are proposed to be deployed to support the excess utilization. One of the critical parameters to be measured is the received signal strength. Most researchers measure their signal strength upon completion of network deployment using third-party software such as InSSiDER, NetSpot, Wifi-Analyzer, and many more. There are limited numbers of research has been done to predict WLAN performance on the signal strength and network latency, especially using mathematical theory [24]–[26]. Measuring receive signal strength is crucial as it indicates the quality of a WLAN. The higher the received signal at the receiver, the better the WLAN performance. These practices are beneficial, especially for post-network deployment but not for the preliminary planning process.

During the preliminary planning process, suitable techniques can be used to predict the potential receive signal strength, such as the single-ray propagation model and two-ray propagation model, such as Friis Transmission, Hata Okumura, Walfish-Ikegami, and Log-Normal propagation model. In WLAN communication, when signals travel over the air, they are exposed to radio frequency (RF) phenomena such as refraction, reflection, absorption, and scattering, affecting the WLAN signal. The author states that most studies adapt the model to mobile network deployment. However, very little has been done in WLAN environments considering path loss propagation in predicting a WLAN performance. Thus, this study focused on predicting received signal strength using a single-ray model called the modified Friis Transmission Equation technique, which considers propagation path loss in the HLI environment.

C. *Friis Transmission*

The Friis Transmission Equation is one of the single-ray propagation models widely used to predict the received signal strength at the end user's devices. This equation predicts received signal strength in an ideal wireless network scenario. It calculates the power received (P_r), given that a known power (P_t) is radiated. This equation assumes the antennas at both the transmitter and receiver are isotropic and in free space. Free space implies no object exists between the transmitter and receiver, also known as line-of-sight (LoS).

The quality of radio frequency signals is affected by various internal and external factors. Internal factors include the antenna transmission power, the power gain, and the distance between the transmitter and the receiver. External factors tend to distort wireless signals caused by their environment as the signal travels from sources to the destinations.

D. Received Singal Strength (RSS)

RSS is defined as a metric used by manufacturers as an indicator of signal strength received by their wireless devices. The RSS is measured in unit dBm (decibel milliwatt). The closer the value of RSS to "0", the stronger the signal that a particular end device will receive. WLAN planning aimed to ensure that S/N (Signal to Noise and Interference ratio) and RSSI (Received Signal Strength Indicator) are satisfied in all targeted areas. The need to measure wireless received signal strength is essential in HLI as it is one of the factors that will determine the type of application and activities to be carried out and the quality of experience (QoE) that the users in the network can obtain. In addition, the demand for online classes requires them to roam from one area to another while accessing their online courses. Table 1 shows the compilation of information from several research studies on the RSSI ranges and ratings that can be used in performing WLAN planning [27]. An excellent signal strength rating is necessary for network services such as VoIP and video streaming.

TABLE I
RSSI RANGES AND RATING

Signal Strength (dBm)	Rating	Required for
>-30 dBm	Amazing	NA
>-65 dBm	Excellent	VoIP/ VoWI-FI, Streaming Video
-65 dBm to -75dBm	Good	Email, web
-75 dBm to -85 dBm	Fair	NA
-85 dBm to -95 dBm	Poor	NA
<= -95dBm	No signal	NA

Thus, a reliable WLAN connection should be available throughout the campus building. Unfortunately, the signal quality will decrease as different materials along the propagation path obstruct it. An approved document by ITU-R (P.2040) has defined the compilation of electrical properties of materials and building loss measurement, and a model should be developed to predict the effect [28]. The coverage of the WLAN signal will decrease because of the impact of various building materials. Table 2 shows compiled information from multiple sources on the radio coverage reduction loss [28], [29]. Thus, a proposed model predicts WLAN signal strength in an HLI environment while considering path loss when the signal penetrates concrete, wood, and glass material.

TABLE II
COVERAGE REDUCTION LOSS

No	Materials	Range of reduction of Loss %	Loss
1	Wood, plaster	0-10%	-8dBi
2	Glass Brick, Press Board	5-35%	-6bBi
2	Brick, Press Board	5-35%	-12dBi
3	Ferro concrete	10-90%	-12dBi
4	Metal, alumni lining	15-19%	-11dBi

II. MATERIALS AND METHOD

A. Materials

Fig. 1 illustrates the model development method used for this research. There are six phases involved in model development. Firstly, a general logical network design for HLI is prepared. In the HLI building environment, WLAN is deployed in various areas such as classrooms, computer labs, libraries, hostels, lecture halls, etc. Different regions use different building materials depending on the function of the areas. Thus, a network designer needs to know the type of building material to ensure that the correct network device specifications, such as transmit power and transmit gain, are proposed correctly, as the usage of building materials can affect the WLAN performance in that area.

Next, the WLAN performance parameter to be measured, signal strength, is identified. Next, the suitable formula and technique to measure signal strength, Friis Transmission, is selected, and all related parameters input to measure the signal strength are identified. The parameter inputs used in Friis Transmission were identified and simulated in the simulation model developed in MATLAB. Lastly, the model is verified by comparing the simulation result with the natural environment testing using third-party software. As distance was one of the factors contributing to the received signal strength, six different distances were tested to study the effect of distances on the received signal strength.

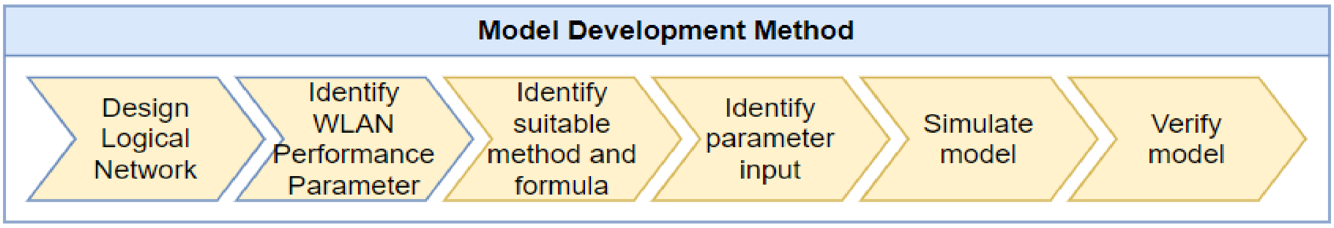

Fig. 1 Model Development Method

Fig. 2 depicts the general logical network design for Malaysia HLI. The model development only focuses on measuring WLAN performance between the end user device and a single access point. The selected performance parameter for this research was the received signal strength.

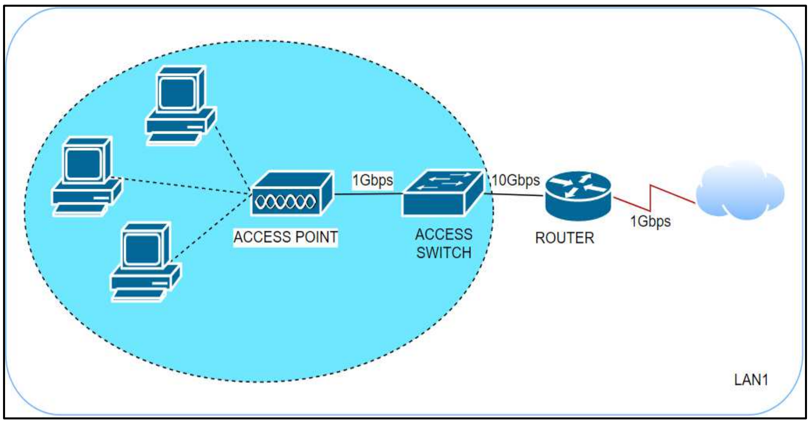

Fig. 2 Logical Network Design

Fig. 3 illustrates the modified method used to predict WLAN signal strength called modified Friis Transmission. To prove the theoretical concept, the original Friis transmission is used to predict received signal strength in the Line-of-sight (LoS) scenario and free path loss between the transmitter and receiver. Secondly, the modified Friis Transmission is used to predict the received signal strength while considering path loss. The parameter input values and unit such as the transmit power (P_{tx}), transmit gain (T_{rx}), received gain (G_{rx}), frequency, distance, and type of obstacle is proposed based on the value used in the real network environment. This method is used to investigate the effect of path loss propagation towards the receive signal strength in HLI WLAN environment.

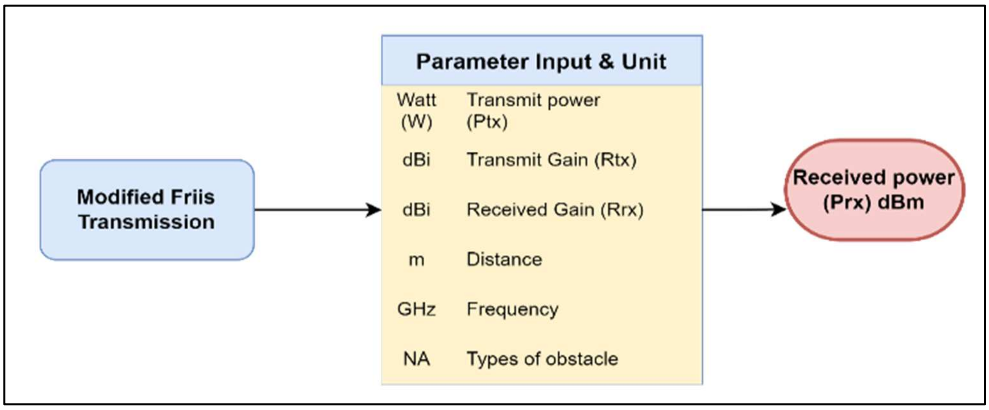

Fig. 3 Modified Friis Transmission to Measure Received Signal Strength and Input

B. *Description of Parameter and Methods Used*

The parameters and methods used in this research are discussed.

1) Original Friis Transmission Equation: Received power refers to the received signal level, which is the signal strength obtained by a laptop or end user's wireless device from an access point's antenna. It is an important factor to determine whether the received signal is good or not. In WLAN, the received power (dBm) can be measured as Received Signal Strength Indicator (RSSI), while for mobile networks, it is measured as Reference Signal Received Power (RSRP) [27]. RSSI is presented in dBm (decibel milliwatt) at the receiver. The mathematical formula to calculate the received power (dBm) using Friis Transmission Equation is shown in Eq. 1.:

$$Prx\ (dBm) = Ptx + Gtx + Grx + 20log10\ (\frac{\lambda}{4\pi Dr}) \quad (1)$$

where the notation of the Friis Transmission is summarized in Table 3.

TABLE III
FRIIS TRANSMISSION NOTATION

Model Parameters	Meaning
Prx	Received power (dBm)
Ptx	Transmit Power (Watt)
Gtx	Transmit Gain
Grx	Receiving Gain
Dr	Distance between transmitter and receiver
λ	Wavelength (frequency in GHz/ speed of light)

2) Model Simulation: Using Friis Transmission equation, a model to measure and predict signal strength in a LoS scenario has been developed and simulated in the MATLAB simulation tool. Eq. 1. is used to calculate the received power (R_{tx}) at the user's end device. The assumption on the input values is made based on the real device environment. Fig. 4 illustrates how the Friis transmission model is used to predict received signal strength. For simulation purposes, only one transmitter and one receiver are involved in predicting signal strength. The parameter input: Ptx, Gtx, Prx, Grx and Dr assumes of the real network. The model was then developed using MATLAB simulation tool.

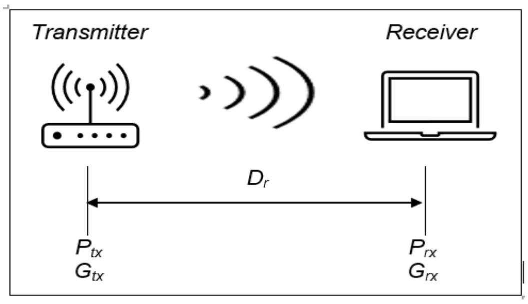

Fig. 4 Network Setup to Measure Received Signal Strength

Fig. 5 shows the simulated model developed in MATLAB before any input values were keyed in. The model can predict the received signal strength when transmitted in both frequencies, 2.4GHz and 5GHz. The Ptx, frequency, and distance units can be changed according to the default unit used by the device's manufacturers. The result of the received signal strength (Prx) will then be displayed in two units, which are Watt (W) and decibel milliwatt (dBm). The assumption value based on the real HLI environment simulates the model.

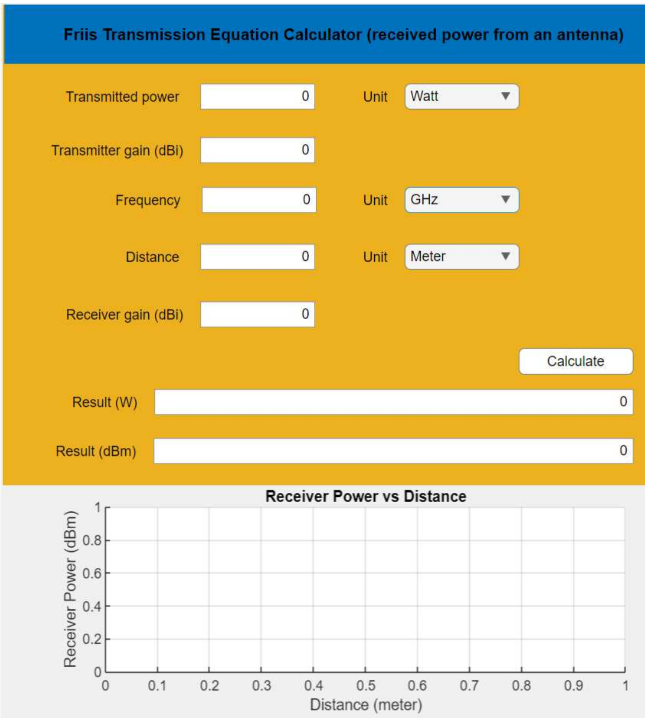

Fig. 5 Simulated model Without Input Values

C. *Testing and Verify Model*

Several scenarios have been created to verify the developed model. Fig. 6 shows the distance measurement done by the research team. The testing was conducted at various distances from five to 30 meters at five meters intervals. Fig. 7 illustrates the real testing design used in conducting lab testing to check signal strength in LoS.

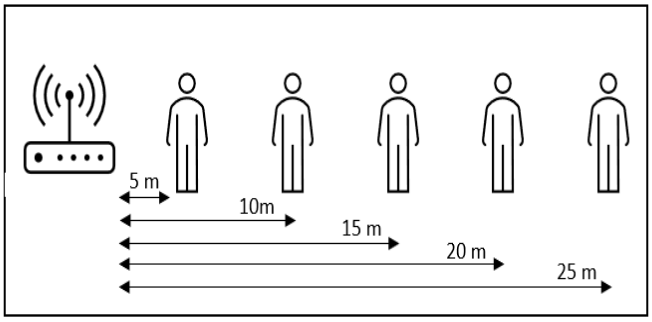

Fig 6 WLAN Signal Strength Testing Diagram at various Distances

Fig 7 Real WLAN Signal Strength Testing in LoS.

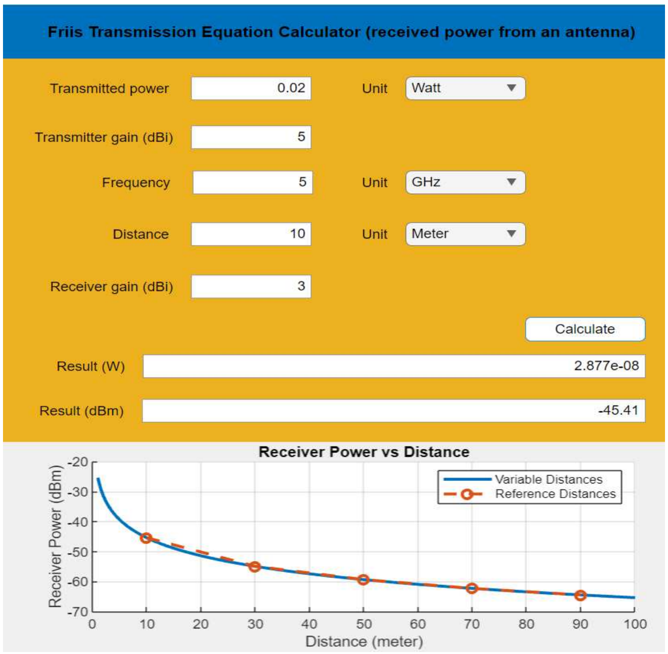

Fig. 8 Example of Model Simulation to Predict Signal Strength Result

The distance between a transmitter to a receiver is measured using measurement tape. It also shows how the AP, and the transmitter were located for the testing purpose. The testing was conducted in UniKL MIIT environment. Using SSID "UniKLTest_5GHz" and "UniKLTest_2.4GHz", the IP address of the access point (AP) was set to "192.1681.1/24" and the end-user obtained the IP address from the built-in DHCP server in the AP. For the receiver, a laptop with the DELL Vostro model is used, while for the transmitter, an access point that supports 802.11ax and 802.11ac is used. To measure the received signal strength at the end device, third-party software called Metageek InSSiDer 5.5.0.0 was used.

Both the sample prediction model and real testing use the same input value: TRX=0.02Watt, TGX=5dBi, frequency=5GHz, distance=100m, and RGX=3dBi

Once the setup was done, the developed model and the real testing were conducted concurrently. The assumption values of Ptx=0.02Watt, Gtx=5dBi, frequency=5GHz, distance=10m, and Grx=3dBi are used to simulate the prediction model. The simulation model predicts the value of Prx. Users can freely change the input unit, and the model will convert the input value accordingly. The model also predicts that the received power (Prx) value at the receiver decreases as the distance between the transmitters increases.

TABLE IV
TESTING RESULTS USING BOTH FRIIS TRANSMISSION AND REAL TESTING

Distance	2.4GHz		5GHz	
	Friis Equation	Real Test	Friis Equation	Real Test
5	-33.02	-38.3	-39.39	-39.1
10	-39.04	-38.2	-45.41	-56.3
15	-42.56	-43.3	-48.93	-58.3
20	-45.06	-50.4	-51.43	-57.5
25	-46.99	-49.8	-53.37	-58.0

A. Scenario A

Simulate the model with LoS. The distance and frequency are 5m, 10m, 15m, and 20m, while the frequency uses 2.4GHz and 5GHz. The testing result is shown in Table 4. In the real network, the signal degraded despite no obstacle between the transmitter and the receiver. This is due to the propagation issue in the environment, degrading WLAN performance.

B. Scenario B

Simulate model with NLoS. The distance and frequency are 5m, 10m, 15m, and 20m, while the frequency uses 2.4GHz and 5GHz. The result is shown in Fig 9 as the real network setup. The distance (D_r) is set for only two different distance values: 5m and 10 m. Testing was done to study the effect of different types of obstacles to see the different received signal strength results for different kinds of obstacles.

Signal Strength vs Type of Obstruction for 2.4ghz			
	Materials	5m	10m
No Obstacles	Glass wall	-35	-43
	Cardboard wall	-35	-46
	Fire door	-35	-46
	Wooden door	-37	-43
	Concrete wall	-35	-46
yes obstacle	Glass wall	-46	-59
	Cardboard wall	-41	-52
	Fire door	-44	-55
	Wooden door	-42	-60
	Concrete wall	-60	-82

Fig. 9 Signal Strength vs Type of Obstruction for 2.4GHz

Fig.9 shows the result of receiving signal strength with reflection to different types of obstruction in frequency 2.4GHz. Glass walls, cardboard walls, fire doors, wooden doors, and concrete walls were the five forms of barrier tested, as shown in the table and graphs. All the readings were taken in two conditions, 2.4GHz and 5GHz, at distances of 5 and 10 meters, with and without blockage. The graph shows that the result is substantially worse when the obstruction is less than 0. However, as you can see, a 10m concrete wall using 5GHz has no data because the link has been disconnected. It demonstrates that the concrete wall has the worst connectivity. Fig. 10 compares received signal strength between different types of obstructions.

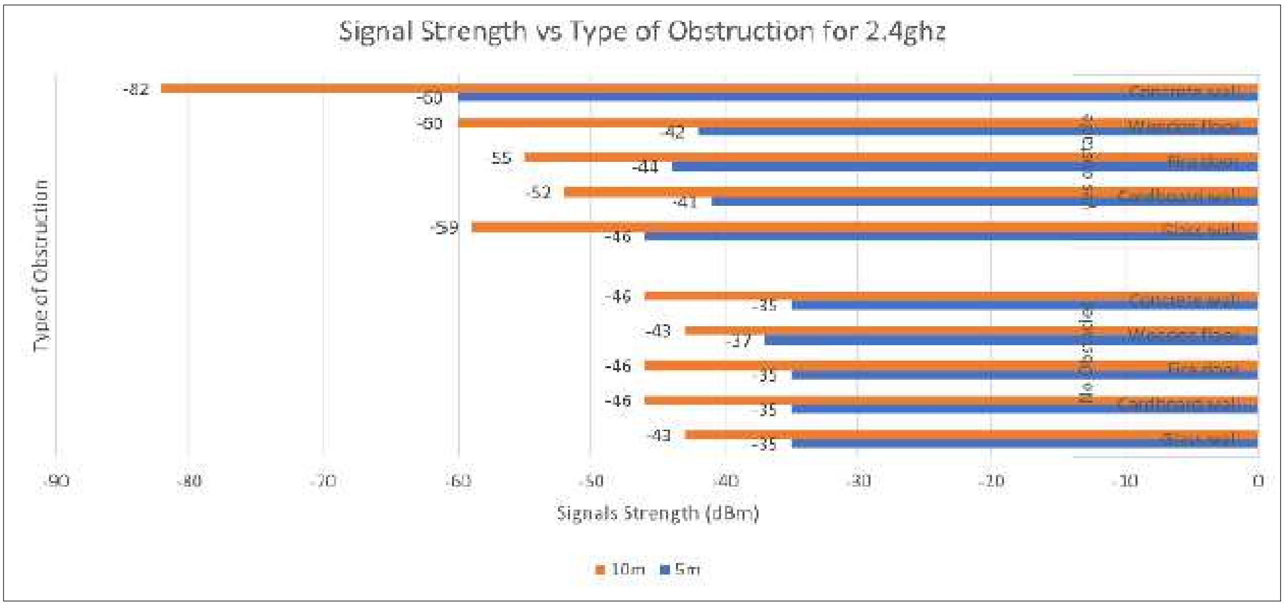

Fig. 10 Comparison Signal Strength vs Type of Obstruction for 2.4GHz

III. Results and Discussion

All the readings were taken in two conditions, 2.4GHz and 5GHz, at distances of 5 and 10 meters, with and without blockage. As seen in the graph, the result is substantially worse when the obstruction is less than 0. However, as you can see, a 10m concrete wall using 5GHz has no data because the link has been disconnected. It demonstrates that the concrete fence has the worst connectivity. Fig. 11 compares received signal strength between different types of obstructions.

As can be seen from the graph, the farther the distance between AP and the receiver, and the more obstructions exist in the network, such as a glass door and a wall, the less connection you will have. The accessibility of the link is affected by the appearance of the blockage. However, due to the low demand for usage in the area, placing two APs in the optimal location is unnecessary. While the blockage in the room impacts signal strength, even with just one AP, it manages to provide the best data rate and signal strength with the best coverage.

Signal Strength vs Type of Obstruction for 5ghz			
	Materials	5m	10m
No Obstacles	Glass wall	-34	-44
	Cardboard wall	-32	-45
	Fire door	-32	-47
	Wooden door	-32	-57
	Concrete wall	-32	-47
yes obstacle	Glass wall	-52	-68
	Cardboard wall	-48	-60
	Fire door	-54	-63
	Wooden door	-58	-71
	Concrete wall	-85	

Fig. 11 Signal Strength vs Type of Obstruction for 5GHz

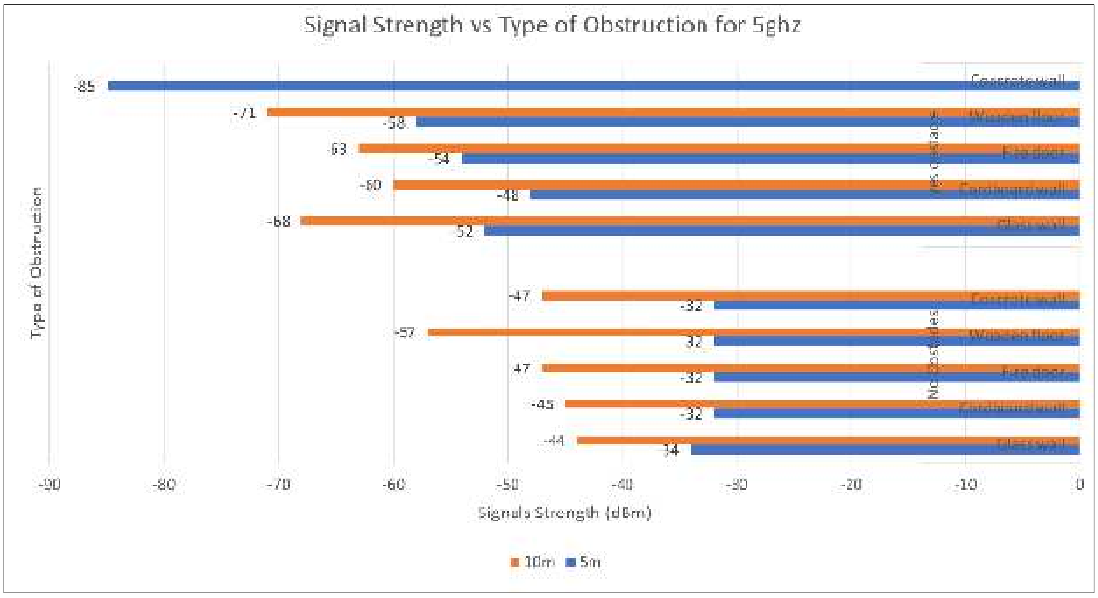

Fig. 12 Comparison Signal Strength vs Type of Obstruction for 5GHz

There can be several reasons why the actual signal strength readings may differ from the calculated values using the Friis transmission equation. Here are a few possible factors:

1) Environmental Factors: The Friis equation assumes free space propagation without obstacles, interference, or multipath effects. The signal can encounter obstacles such as walls, buildings, or other objects that can attenuate or reflect the signal, leading to variations in signal strength [28].

2) Antenna Characteristics: The gains of the transmitter and receiver antennas play a crucial role in signal strength. The actual antenna characteristics, including the radiation pattern, efficiency, and polarization, may deviate from the assumed values used in the calculations [30].

3) Signal Interference: The presence of other devices or networks operating on the same frequency can cause interference, leading to signal degradation. The Friis equation does not account for interference, which can impact the actual received signal strength.

4) Receiver Sensitivity: Different receivers may have varying sensitivity levels, noise figures, or filtering characteristics, which can impact the received signal strength.

It is essential to consider that the Friis transmission equation provides an estimation based on certain assumptions and ideal conditions. Real-world wireless environments are complex, and various factors can influence the actual signal strength observed in practice.

IV. Conclusion

This article has shown the developed model using the Friis Transmission equation to predict the received signal strength in the line of sight and non-line of sight scenario tested in the HLI WLAN environment. The testing significantly affects the received signal strength by different building materials, which are considered obstructions as the testing object. This model can be used to understand the behavior of other building materials towards the HLI WLAN environment, where concrete walls have the most significant impact on the received signal strength. The proposed simulated- model can be used to assist network designers in HLI as a preliminary result before WLAN planning. As for future research, the hybrid Friis transmission and Log normal Shadowing propagation Model could be tested to see more accurate results in predicting WLAN signal strength in the HLI environment.

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