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Study on path loss attenuation in indoor environment of wireless telecommunication system at 1.8 GHz

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Abstract: To improve the performance of wireless communications in indoor environment, it is important to optimize the signal quality by reducing the error rate between the received signal strength based on experimental data and estimating data. Due to the complexity of modern building layouts and construction materials, estimating received signal strength values based on these structural elements is challenging. The aim of this paper is to analyze received signal strength of the specific area by using the path loss exponent model of ray tracing techniques. In indoor environments, modeling radio wave propagation involves estimating the received signal strength at various points based on the layout and geometry of the space. This study involved three placement of 1.8 GHz AAU5940 Wall Mounted transmitters at height with 11.12 m and at different distances with 44.81 m, 95.4 m, and 108.2 m of specific receiver building. The Received Signal Strength Indicator (RSSI) readings are typically recorded to analyze and understand the ray tracing technique characteristics in a wireless communication environment. This paper presents analytical result of some practical experiments that helps to build an optimized signal quality for indoor environment using mathematical modelling with the help of MATLAB software.

Keywords: wireless communication; path loss exponent model; ray tracing techniques; mathematical modelling

1. Introduction

The wireless propagation channel is the medium over which transportation of the signals from the transmitter (Tx) to the receiver (Rx) occurs, and as a consequence, channel properties determine the ultimate performance limits of wireless communications, as well as the performance of specific transmission schemes and transceiver architectures (Ali et al., 2022).Channel modelling is the process of studying and representing the behaviour of the communication channel in order to design and optimize communication systems for reliable and efficient data transmission. The use of wide bandwidths (e.g., ≥100 MHz) in 5G and future wireless communication systems will enable multi-Gbps data rates for mobile devices and will usher in many new applications (Nordin et al., 2019). The fifth generation (5G) systems enable people to access and share information in a wide range of scenarios with extremely low latency and very high data rate. It should achieve 1000 times the system capacity, 100 times the data rate, 3–5 times the spectral efficiency, and 10–100 times the energy efficiency with respect to the current fourth generation (4G) (Zhang et al., 2020). In addition to the various propagation paths, the different channel scenarios including static and time-varying environments need to be considered. Benefiting from the very large bandwidth, mmWave communication is able to provide a data rate of several gigabits per second with ease. However, the propagation at higher frequencies results in significant path loss (Xing et al., 2021).

Due to the crowded and modern design of buildings, it is difficult to estimate and to recommend the received signal level at the receiver. The increasing mobile users and complex structure of building force to become upgrade from 1st generation (1G) to 5th generation (5G) according to the supported

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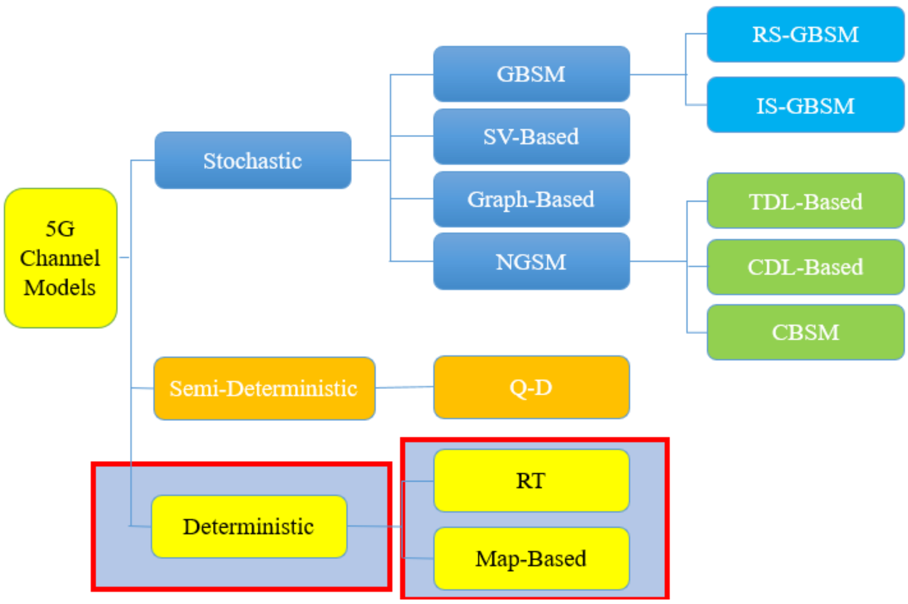
characteristics such as analog data, digital data, bandwidth, data transfer rate and so on (MacCartney et al., 2015; Xing & Rappaport, 2021; Labibah Amelia et al., 2022). Most modern buildings are constructed from materials that reflect mobile signals. Metal, glass and concrete are notoriously difficult for mobile signal to penetrate (Sun et al., 2018; Pimienta-Del-Valle et al., 2021; Getahun & Rajkumar, 2023). This also causes more received signal strength losses. There are a variety of solutions that can improve signal, that is why, it forces to conduct this research work to overcome the received signal strength losses problem in indoor environment by improving channel model performance (Li et al., 2019).

In indoor environments, there are always facing problems with the disconnection mobile signal. The aim of the research works is to analyze the existing channel model for mobile telecommunication system at Polytechnic University (Maubin). This research is to optimize the path loss model in indoor environment and then improve the signal strength in wireless telecommunication system.

2. Methods

This research work is approached the deterministic 5G channel model which includes ray tracing techniques and map-based techniques. The deterministic channel modelling in telecommunication indicates to a network behavior or communication model that is described by predictability, reliability, and a high degree of control over various network parameters. In a deterministic 5G network, the performance and behavior of the network are uniform and can be accurately determined as shown in Figure 1.

Figure 1. Block Diagram of Analyzing Existing Channel Model (Wang et al., 2018)



2.1 Research design

The following steps for doing research on mathematical modelling are based on the design of wireless propagation channel. The research directions are literature review and problem statement, conduct the experiments, analyze the wireless channel propagation models, improve and optimization of propagation model and performance evaluation and accuracy. Firstly, conducting literature studies, namely conducting research and data documentation related to the problems in this final project, articles, references, journals, or other sources related to discussions. And then, installing applications, namely installing software applications, G-Net Track Lite as supporting software in this study. After that, conducting a location survey, which is a research location at the Polytechnic University (Maubin). Then, determine the operators widely used by users, namely Atom, MyTel, Ooredoo and MPT operators. However, from these three providers, there are problems with the signal quality generated at the route point on the Polytechnic University (Maubin) campus. Therefore, the test experiments of MPT operator are doing

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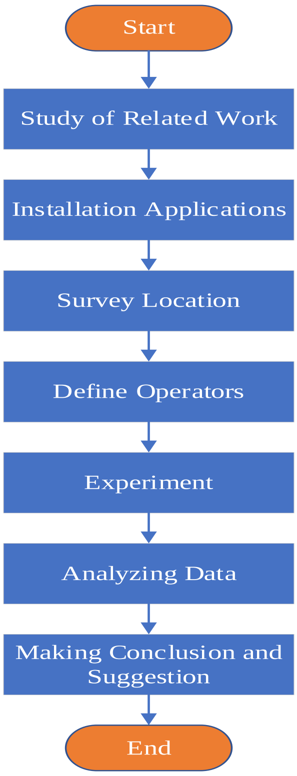
with android phone. And then analyzed the results of data from experiments. Finally, explain the results that have been achieved, along with suggestions for the development of further research. Figure 2 shows the block diagram of overall research work.

Figure 1. Flow chart of research work



2.2 Indoor radio propagation measurements

2.2.1 Reference signal received power of mobile telecommunication

Reference Signal Received Power (RSRP) is a crucial parameter in telecommunications, especially in cellular networks like LTE (Long Term Evolution) and 5G. It represents the strength of the signal as received by the user equipment (UE) from the serving cell's base station (eNodeB in LTE, gNodeB in 5G). RSRP is measured in dBm (decibels referenced to one milliwatt) and provides insights into the quality and strength of the connection between the UE and the base station. The RSRP value of a mobile receiver is preceded by a negative sign, and its unit is dBm. This value is linked to the received signal strength from a tower to a device. The variation of RSRP value ranges can be attributed to cellular carriers. However, −80 dBm or high contributes to the excellent coverage area of a device with optimum signal strength. Table 1 shows the RSRP value range for LTE and 5G communication systems (Oluseun et al., 2020; Geok et al., 2018).

Table 1. Key parameters of RSRP value

RSRP	Signal strength	Description
>= -80 dBm	Excellent	Strong signal with maximum data speeds
-80 dBm to -90 dBm	Good	Strong signal with good data speeds
-90dBm to -100 dBm	Fair to poor	Fair but useful, fast and reliable data speeds may be attained, but marginal data with drop-outs is possible and performance will drop drastically.
<=-100 dBm	No signal	Disconnection

2.2.2 G-NetTrack lite software

G-NetTrack Lite is an application that can be downloaded to Android phones through the Play Store application which helps monitor 4G signal performance via mobile phone. This app is to see if RSRP, RSRQ, and SNR are rated well in the environment to determine the signal quality area (Boccardi et al., 2014; Al-Hourani et al., 2014). Software equipment uses a supporting application, namely the G-NetTrack Lite application. The following Figure 3 shows the appearance of the application on an Android phone.

Figure 3. Measuring RSRP result with android phone

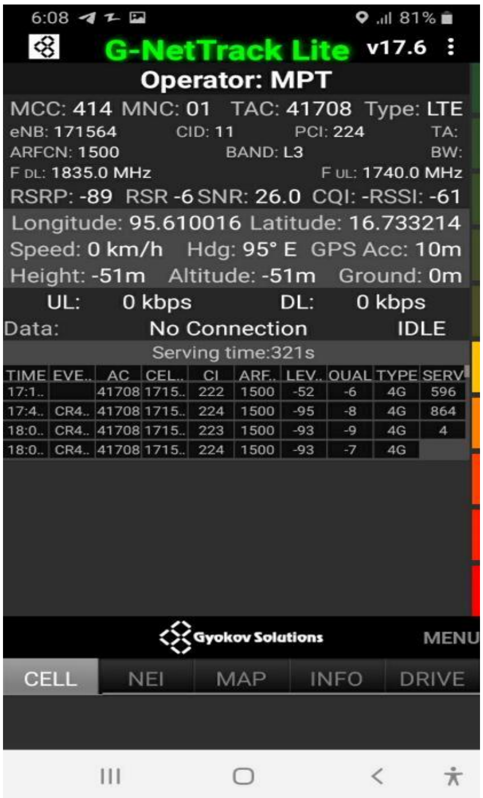
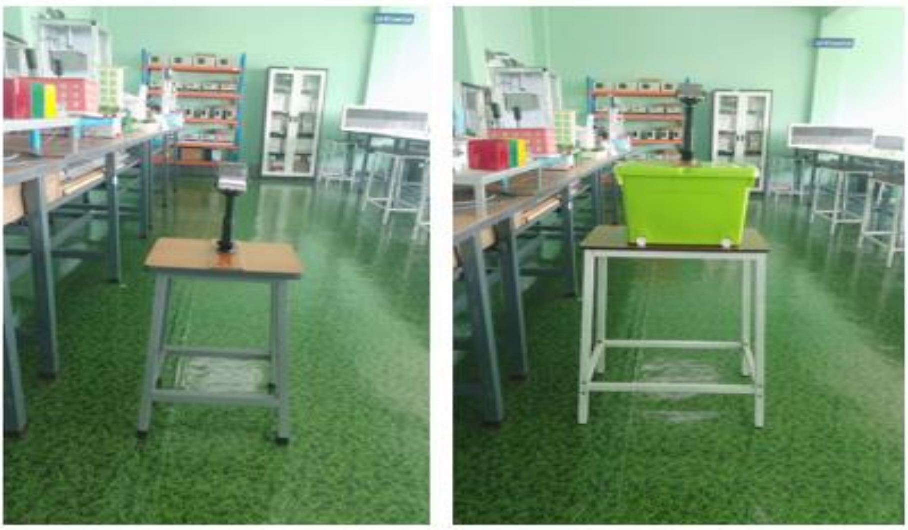


Figure 4 shows the strength of the signal as received by the user equipment (UE) from the base station at a distance of 15 feet by 30 feet for 3ft and 5ft height.

Figure 4. Measuring RSRP Result for 3ft and 5ft height



2.3 Implementation of path loss exponent model

The path loss exponent (PLE) is a fundamental parameter in wireless communication that affects how signal strength diminishes with distance between transmitter and receiver. The height of the transmitting and receiving antennas can affect the PLE. Understanding the PLE is vital for designing and optimizing wireless communication systems.

Table 2. Path loss exponent value for different environment

Environment	Path Loss Exponent, n
Free space	2
Urban area	2.7 to 3.5
Shadowed urban	3 to 5
In building line-of –site	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

For free space path loss model is calculated by:

$$PL(dB) = 32.5 + 20\log_{10} f\,(MHz) + 20\log_{10} d\,(km) \tag{1}$$

where f is carrier frequency in MHz, d is distance between transmitter and receiver in km. For long-distance/ one slope path loss model is expressed by:

$$PL(d) = PL(d_O) + 10n\log\left(\frac{d}{d_O}\right) \tag{2}$$

where n is the path loss exponent, d is the distance between transmitter and receiver in meters, d_O is the close-in reference distance in meters, $PL(d_O)$ is the free space path loss where $PL(d_O)=20\log(f)-28$, frequency in MHz.

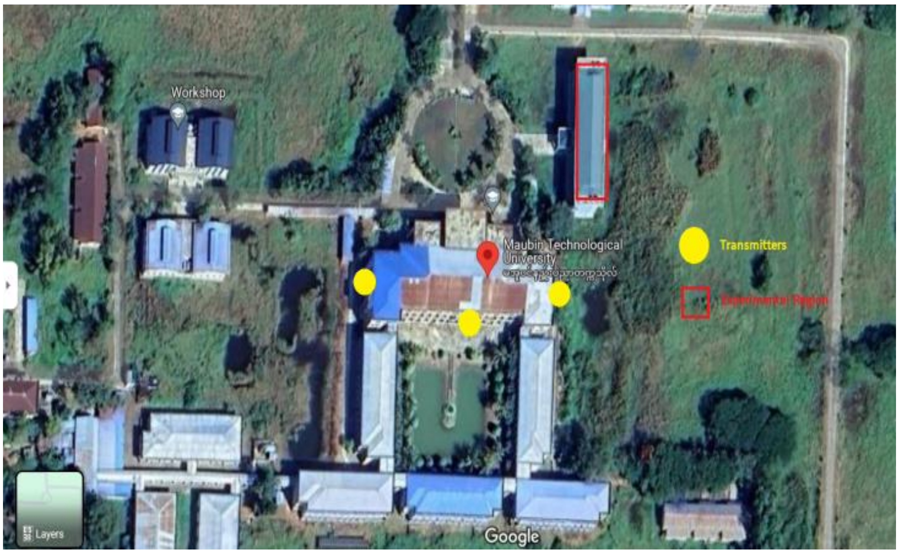


Figure 5. Experimental environment at Polytechnic University (Maubin)

Experimental 3-storyed building at Polytechnic University (Maubin) was selected for measuring the RSRP with the G-NetTrack Lite software, which is one of the various signals transmitted from the base station (MPT) using the mobile communication network. At the ground floor, first floor and second floor of this building have four rooms respectively, the signal strength was measured at 390 points at a height of 3 feets and 5 feets from the floor with the same distances. The distance between every 2 points is 5 feets. In the research work, the experiments data are used in the following table by the help of Matlab simulation.

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Table 3. Specification of experiments

No.	Description	Specification	Remark
1	Transmitter type	AUU5940	MPT
2	Transmitted power	16.8dBm	for Exp
3	Transmitter gain	14.5dBi	
4	Transmitter height	11.12m	from ground
5	Number of APs	3	
6	Receiver height	3ft, 5ft	from floor
7	Building dimension	192'x 38'	
8	Working frequency	1.8 GHz	

3. Results and discussion

In this section, we conduct experimental evaluations on the various analytical related to wireless communication channels. The simulation analysis was carried out based on the optimized path loss exponent value for specific rooms (obstructed in building range 4 to 6), f=1800 MHz and $d_{0=}$ 1 m by using MATLAB programming language with the version of 2015. This result shows the optimized minimum error values between RSSI values by path loss model and by experiments of twelve rooms of experimental building. The optimized minimum error values show the red small circles and maximum error value shows green small circles for experimental rooms respectively. Figure 6 shows the simulation results of minimum and maximum RSSI error value between experimental data and estimated data of A1/1 room at ground floor at Polytechnic University (Maubin). This error rate can be accepted to recommend mobile signal losses.

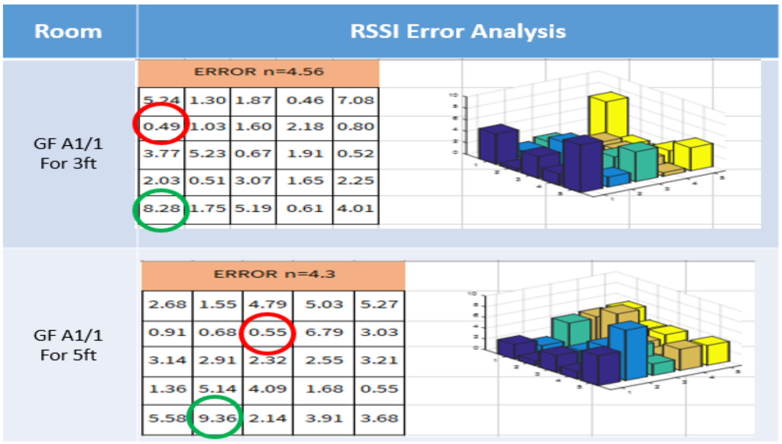


Figure 6. Error analysis between simulation and measurements result at room A1/1

Figure 7 illustrates the minimum and maximum RSSI error value between experimental data and estimated data of A1/2 room at ground floor for 3ft and 5ft receiver heights at Polytechnic University (Maubin).

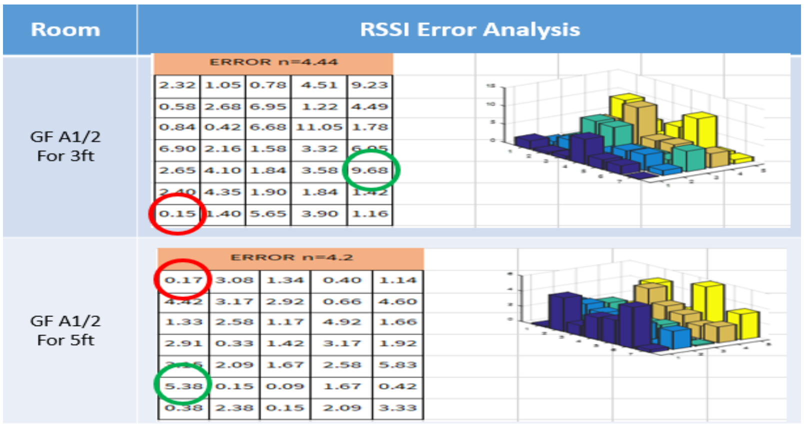
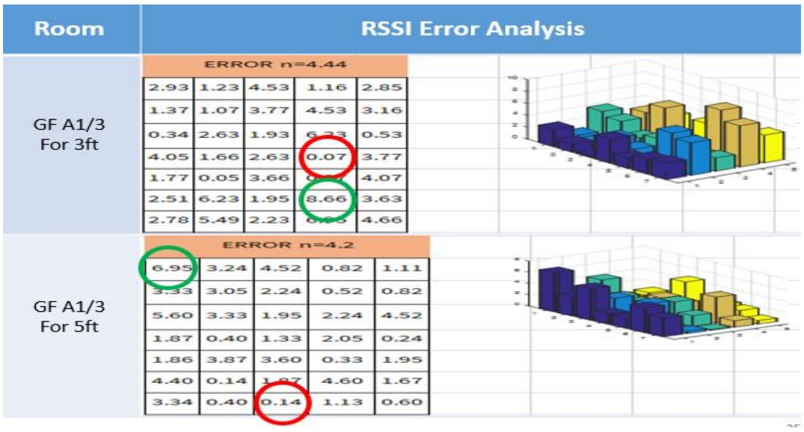


Figure 7. Error Analysis Between Simulation and Measurements result at Room A1/2

Figure 8 exhibits the simulation results of minimum and maximum RSSI error value between experimental data and estimated data of A1/3 room at ground floor for 3ft and 5ft receiver heights at Polytechnic University (Maubin).

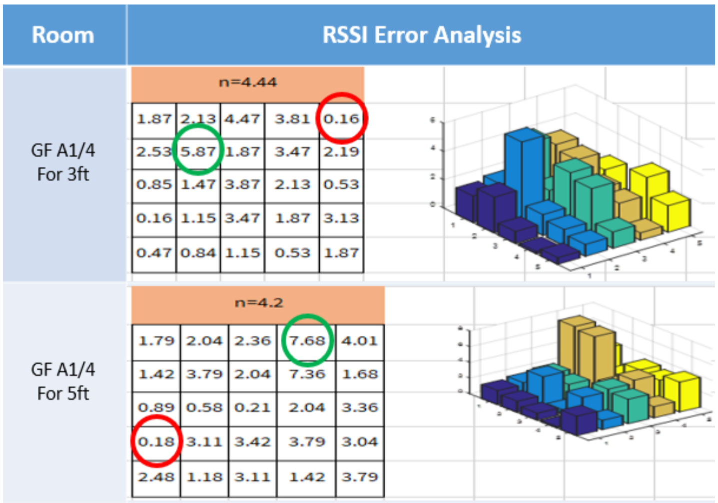
Figure 8. Error Analysis Between Simulation and Measurements result at Room A1/3



Room	RSSI Error Analysis				
GF A1/3 For 3ft	ERROR n=4.44				
	2.93	1.23	4.53	1.16	2.85
	1.37	1.07	3.77	4.53	3.16
	0.34	2.63	1.93	6.23	0.53
	4.05	1.66	2.63	0.07	3.77
	1.77	0.05	3.66	[illegible]	4.07
	2.51	6.23	1.95	8.66	3.63
	2.78	5.49	2.23	[illegible]	4.66
GF A1/3 For 5ft	ERROR n=4.2				
	6.95	3.24	4.52	0.82	1.11
	3.33	3.05	2.24	0.52	0.82
	5.60	3.33	1.95	2.24	4.52
	1.87	0.40	1.33	2.05	0.24
	1.86	3.87	3.60	0.33	1.95
	4.40	0.14	1.87	4.60	1.67
	3.34	0.40	0.14	1.13	0.60

Figure 9 demonstrates the RSSI error analysis for difference receiver heights of A1/4 room at ground floor at Polytechnic University (Maubin).

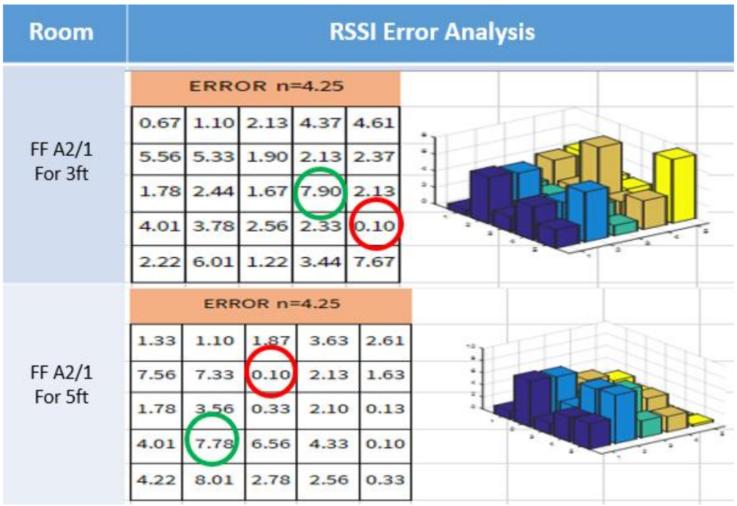
Figure 9. Error analysis between simulation and measurements result at room A1/4



Room	RSSI Error Analysis				
GF A1/4 For 3ft	n=4.44				
	1.87	2.13	4.47	3.81	0.16
	2.53	5.87	1.87	3.47	2.19
	0.85	1.47	3.87	2.13	0.53
	0.16	1.15	3.47	1.87	3.13
	0.47	0.84	1.15	0.53	1.87
GF A1/4 For 5ft	n=4.2				
	1.79	2.04	2.36	7.68	4.01
	1.42	3.79	2.04	7.36	1.68
	0.89	0.58	0.21	2.04	3.36
	0.18	3.11	3.42	3.79	3.04
	2.48	1.18	3.11	1.42	3.79

Figure 10 reveals the simulation results of minimum and maximum RSSI error value between experimental data and estimated data of A2/1 room at first floor at Polytechnic University (Maubin).

Figure 10. Error analysis between simulation and measurements result at room A2/1



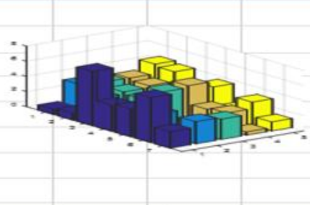
Room	RSSI Error Analysis				
FF A2/1 For 3ft	ERROR n=4.25				
	0.67	1.10	2.13	4.37	4.61
	5.56	5.33	1.90	2.13	2.37
	1.78	2.44	1.67	7.90	2.13
	4.01	3.78	2.56	2.33	0.10
	2.22	6.01	1.22	3.44	7.67
FF A2/1 For 5ft	ERROR n=4.25				
	1.33	1.10	1.87	3.63	2.61
	7.56	7.33	0.10	2.13	1.63
	1.78	3.56	0.33	2.10	0.13
	4.01	7.78	6.56	4.33	0.10
	4.22	8.01	2.78	2.56	0.33

Figure 11 reveals the minimum and maximum RSSI error value between experimental data and estimated data of A2/2 room at first floor at Polytechnic University (Maubin).

Figure 11. Error analysis between simulation and measurements result at room A2/2

Room	RSSI Error Analysis
FF A2/2 For 3ft	ERROR n=4.3

0.68	3.42	3.16	3.11	4.38
0.94	[illegible]	2.58	2.84	4.11
7.19	0.06	2.32	2.58	0.16
[illegible]	[illegible]	4.06	4.32	3.58
3.68	2.44	0.19	1.94	1.32
5.93	0.68	0.44	2.19	3.06
2.16	2.93	2.68	0.44	1.19



Room	RSSI Error Analysis
FF A2/2 For 5ft	ERROR n=4.25

7.40	2.15	1.89	[illegible]	0.36
1.65	1.60	1.85	0.11	3.38
7.90	4.65	4.40	2.15	2.89
8.15	[illegible]	2.65	4.40	0.85
4.39	11.15	4.90	4.65	1.40
6.63	[illegible]	3.15	2.90	1.65
6.87	7.63	3.39	5.15	1.90

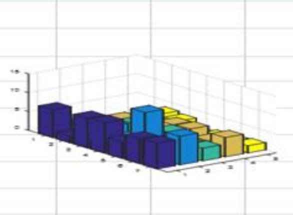
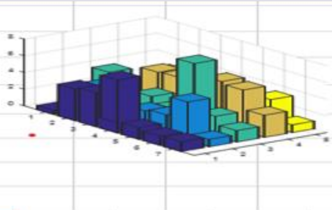


Figure 12 indicates the simulation result of the minimum and maximum RSSI error value between experimental data and estimated data of A2/3 room at first floor at Polytechnic University (Maubin).

Figure 12. Error analysis between simulation and measurements result at room A2/3

Room	RSSI Error Analysis
FF A2/3 For 3ft	ERROR n=4.3

0.50	0.79	3.91	0.39	2.69
3.79	3.50	0.21	4.09	3.61
[illegible]	0.21	2.50	4.21	0.09
6.35	2.07	1.79	4.50	[illegible]
[illegible]	2.35	7.93	5.21	1.50
1.11	4.62	2.35	4.93	3.21
1.16	0.89	1.38	2.65	0.93



Room	RSSI Error Analysis
FF A2/3 For 5ft	ERROR n=4.25

6.25	0.04	4.67	0.37	1.93
2.53	4.25	2.96	2.67	4.37
[illegible]	0.53	3.25	4.96	2.67
9.08	4.81	2.53	5.25	4.96
5.36	3.08	0.81	5.53	5.25
[illegible]	1.36	7.08	1.81	3.53
0.11	7.62	5.36	6.08	1.81

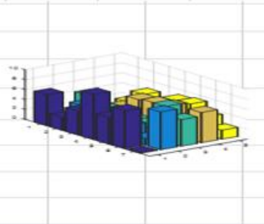
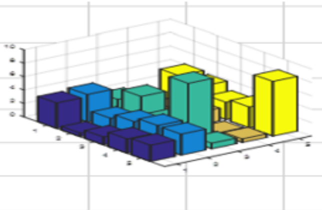


Figure 13 illustrates the minimum and maximum RSSI error value between experimental data and estimated data of A2/4 room at first floor at Polytechnic University (Maubin).

Figure 13. Error analysis between simulation and measurements result at room A2/4

Room	RSSI Error Analysis
FF A2/4 For 3ft	ERROR n=4.2

3.79	4.10	2.42	0.26	4.08
0.52	1.79	4.10	1.42	3.74
1.17	2.52	1.79	1.90	2.58
2.12	3.17	8.52	0.21	3.10
2.42	3.12	0.83	0.52	8.15



Room	RSSI Error Analysis
FF A2/4 For 5ft	n=4.1

5.75	0.56	5.13	3.81	1.49
0.05	2.25	5.44	2.13	3.81
2.34	2.05	5.75	5.44	1.87
7.64	1.66	4.05	5.75	0.44
1.92	0.64	0.34	1.95	0.31

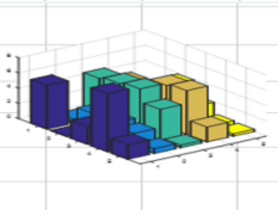
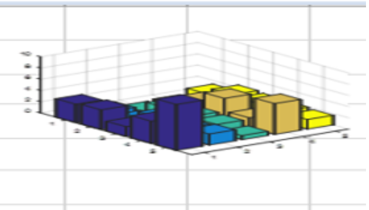


Figure 14 shows the simulation results of minimum and maximum RSSI error value between experimental data and estimated data of A3/1 room at second floor at Polytechnic University (Maubin).

Figure 14. Error analysis between simulation and measurements result at room A3/1

Room	RSSI Error Analysis				
SF A3/1 For 3ft	ERROR n=4.25				
	3.29	1.05	0.18	0.42	1.34
	3.51	0.71	1.95	2.18	2.42
	1.74	2.49	1.71	3.95	2.18
	3.96	1.74	1.49	1.71	1.95
	8.18	1.96	0.74	5.49	1.71
SF A3/1 For 5ft	ERROR n=3.9				
	0.17	2.04	3.26	3.47	5.69
	2.38	5.83	5.04	5.26	5.47
	3.41	1.62	6.83	3.04	5.26
	2.79	1.41	1.38	2.83	3.04
	2.99	2.79	0.41	2.62	0.83



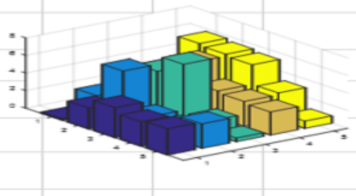
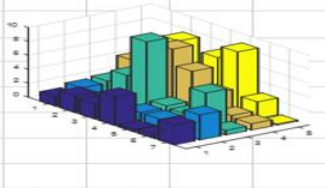


Figure 15 demonstrates the RSSI error analysis for difference receiver heights of A3/2 room at second floor at Polytechnic University (Maubin).

Figure 15. Error analysis between simulation and measurements result at room A3/2

Room	RSSI Error Analysis				
SF A3/2 For 3ft	ERROR n=4.25				
	1.35	1.91	2.17	4.43	3.70
	2.40	0.35	3.91	4.17	7.43
	2.15	0.60	9.65	7.91	2.83
	4.10	1.15	1.40	5.65	6.91
	0.34	1.10	1.15	3.40	8.65
	0.58	0.66	5.10	1.15	2.40
	2.82	3.58	0.66	0.90	0.15
SF A3/2 For 5ft	ERROR n=4.1				
	5.51	2.26	1.99	2.24	3.50
	1.76	1.49	1.74	0.01	3.24
	2.00	0.76	0.51	[illegible]	5.01
	0.24	5.00	2.76	2.51	1.26
	6.47	3.24	1.00	1.24	0.49
	4.70	1.47	5.24	5.00	1.76
	4.93	3.70	2.53	2.76	4.00



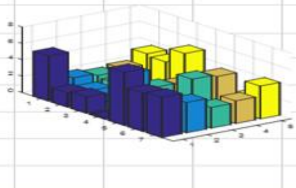


Figure 16 reveals the simulation results of minimum and maximum RSSI error value between experimental data and estimated data of A3/3 room at second floor at Polytechnic University (Maubin).

Figure 16. Error analysis between simulation and measurements result at room A3/3

Room	RSSI Error Analysis				
SF A3/3 For 3ft	ERROR n=4.25				
	0.19	1.90	3.39	2.31	6.01
	4.47	0.19	2.90	0.61	4.31
	4.75	2.47	1.19	1.10	4.61
	7.03	4.75	2.47	0.81	2.90
	1.30	0.97	0.75	4.53	4.81
	5.57	3.30	5.03	2.25	1.47
	1.83	1.57	3.30	1.97	0.25
SF A3/3 For 5ft	ERROR n=4.0				
	1.92	0.35	3.63	2.09	1.81
	4.19	0.08	2.65	2.37	2.09
	0.45	0.19	1.08	1.35	0.37
	2.71	4.45	2.19	1.08	2.65
	0.97	4.71	4.45	1.19	3.08
	1.22	4.97	6.71	0.55	1.19
	0.53	0.78	2.97	0.29	2.55

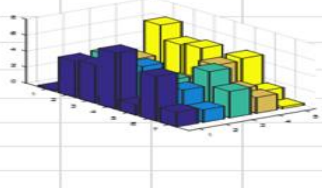


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Figure 17 indicates the simulation result of the minimum and maximum RSSI error value between experimental data and estimated data of A3/4 room at second floor for different heights at Polytechnic University (Maubin).

Figure 17. Error analysis between simulation and measurements result at room A3/4

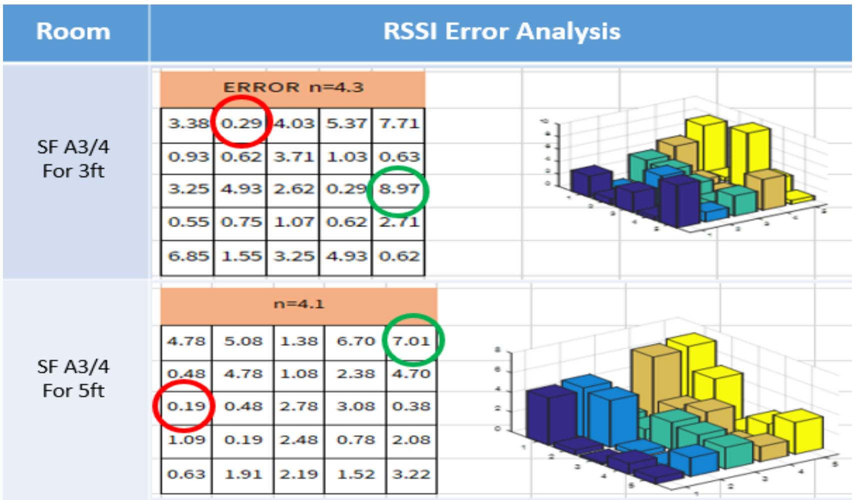

Table 4. Comparison between simulation and measurement results using G-Net track lite software

Sr. No	Experimental rooms	Receiver height	Path loss exponent PLE (n)	Error analysis between simulation and measurements result	
				Minimum error (dBm)	Maximum error (dBm)
1	A1/1	3 ft	4.56	0.46	8.28
2	A1/2	3 ft	4.44	0.15	9.68
3	A1/3	3 ft	4.44	0.07	8.66
4	A1/4	3 ft	4.44	0.16	5.87
5	A2/1	3 ft	4.25	0.10	7.90
6	A2/2	3 ft	4.3	0.06	7.19
7	A2/3	3 ft	4.3	0.21	7.93
8	A2/4	3 ft	4.2	0.26	8.52
9	A3/1	3 ft	4.25	0.18	8.18
10	A3/2	3 ft	4.25	0.15	9.65
11	A3/3	3 ft	4.25	0.19	7.03
12	A3/4	3 ft	4.3	0.29	7.71
13	A1/1	5 ft	4.3	0.55	9.36
14	A1/2	5 ft	4.2	0.09	5.83
15	A1/3	5 ft	4.2	0.14	6.95
16	A1/4	5 ft	4.2	0.18	7.68
17	A2/1	5 ft	4.25	0.10	7.78
18	A2/2	5 ft	4.25	0.11	11.15
19	A2/3	5 ft	4.25	0.04	9.08
20	A2/4	5 ft	4.1	0.05	7.64
21	A3/1	5 ft	3.9	0.17	6.83
22	A3/2	5 ft	4.1	0.01	6.47
23	A3/3	5 ft	4.0	0.08	6.71
24	A3/4	5 ft	4.1	0.19	4.78

Table 4 shows the comparison of experimental data and estimating data of the research work in details. For different receiver height of experimental room, calculated the values of path loss exponent and found the minimum error value and maximum error value between simulation and measurement results using G-Net Track Lite software. For 3ft receiver height, the minimum path loss exponent value is 4.25 and the maximum path loss value is 4.56. For 5ft receiver height, the minimum path loss exponent value is 3.9 and the maximum path loss value is 4.3. Therefore, the height of the transmitting and receiving antennas can affect the PLE. For all conduction experiments, interfere and path loss attenuation due to being human are not analyzed. It should be extended for estimation. In this research, mobility of receiver is not considered during conduction experiments. More complex indoor infrastructure is also used to conduct experiment and to estimate for further network design. As outdoor obstacle between Tx-Rx is totally not included to analyze RSSI values, weather condition and outdoor barrier are also important for network engineer in designing the specific organization. Further researcher should conduct experiments and should estimate RSSI value in comparing these research outcomes with different experimental region (organization) at different frequencies ranges. In all experiments, there are only 3 APs used in evaluation.

This research work shows obviously the area of mobile phone signal strength levels for all rooms of standard experimental region. It helps exactly mobile phone network designing engineers to estimate for fulfillment of the required mobile computing area. Also these outstanding research result recommends RSSI values for not only mobile phone customers but also network engineers. By using mentioned research results, the further researcher should have to use them to upgrade and to extend experimental region for later mobile communication system called later 5G system, 6G and so on and also need to compare with those results to recommend.

4. Conclusion

The MIMO technology is rapidly developed recently. Estimation of received signal strength in wireless communication should be actually analyzed in MIMO technology. The resultant transmitted power is calculated with respect to allocation of AP (Access Point) by using vector summation theory. As the distance between Tx-Rx are vary according to the allocation of different antennas, the related distance between Tx-Rx is assumed as average levels. At the receiving point (Rx), there may be more than one input signal according to the nearby many transmitters (Tx) allocation, as there are three APs in the given experimental region. That is why, the resultant transmitted power affects to every receiving point. Due the analytical result, the RSSI error values are obviously decreased according to the optimization of resultant power. The received signal strength also depends on the environment of experimental region, i.e the dimension of room and building structure. The ray tracing technic is more accurate in estimation of indoor received signal strength than any other estimating models. The dimension of room also affects the received and transmitted signals, as there is the fluctuation of complex structure.

Author's Declaration

Author contribution

Myint Myint Mon: data collection, data analysis, methodology, draft preparation, correspondence. **Mya Mya Aye**: supervision, methodology. **Lei Lei Yin Win**: supervision, validation. **Thanda Win**: supervision, reviewing and editing.

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Conflict of interest

The authors affirm that they do not possess any identifiable conflicting financial interests or personal associations that could have potentially influenced the findings presented in this paper. Additionally, they confirm that they have not obtained any research grants from funding organizations or financial backing to attend symposiums.

Ethical clearance

This research does not involve humans as subjects.

AI Statement

This article is the original work of the author without using AI tools for writing sentences and/or creating/editing table and figures in this manuscript. The grammatical structure of this article was improved by using ChatGPT and the authors have rechecked the accuracy and correctness of the generated sentences with the topic and data of this study. The data and language use in this article have been validated and verified by an English language expert and none of the AI-generated sentences include in this article.

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