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Analysis of the selection of propagation models from outside into the building at 1800 MHz and 2100 MHz

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Abstract: Wireless internet service in educational buildings plays a crucial role in telecommunications for the knowledge sharing process. Therefore, various factors that may limit internet services coverage in the building should be eliminated or reduced. One such factor is path losses. Path losses are caused by multiple obstacles between the transmitting and receiving antennas. The problem of path losses in the education building can be solved by providing signal booster devices or Wireless Fidelity (Wi-Fi). But not all college buildings have such tools. Besides, WiFi devices also have limitations on bandwidth and the number of users. Thus, mobile communication devices or smartphones located inside the education buildings still need internet service coverage from the transmitter antenna outside the building. An accurate propagation model is required so that the transmitter antenna outside the building can provide internet service coverage to the inside of the building. This paper had been analyzed the selection of propagation models using three validation formulas, namely Mean Error (ME), Root Mean Square Error (RMSE), and Standard Deviation Error (SDE). This paper used several propagation models, namely the 3GPP Model, Winner+ Model, and COST231 Model. Based on the analysis of calculation and measurement data, it is known that the COST231 model is the most accurate because it has the lowest ME, RMSE, and SDE values.

Keywords: 3GPP model; COST231 model, Path losses; propagation from outside into the building; propagation model; Winner+ Model.

INTRODUCTION

The increase in the number of mobile communication devices is due to the increasing human need to share easy, fast, and flexible information at a low cost. Nowadays, most of the users of mobile communication devices are in the building. Thus, the smooth communication services for mobile communication devices in the building become very important. One factor that can interfere with the communication process in the building is the level of receiving signals received by mobile communication devices is inadequate (Lee, 2021). The issue can be addressed by providing a signal power booster device or Wi-Fi device. However, not all buildings have such tools. Thus, mobile communication devices in the building still require an adequate level of receiving a signal from the transmitter antenna outside the building.

To ensure that mobile communication devices located indoors get an adequate receiving signal level from an outdoor transmitter, a propagation model is required to predict the power level lost during propagation (path loss). The outdoor to indoor propagation model is necessary to predict the path losses when the signal propagates from the outside into the building. The prediction of path losses from the outside into the building is more complicated than others (outdoor propagation or indoor propagation) because predictions of path losses from outside into the building include predicting path losses outside the building, penetrating the outer walls of the building, and inside the building (Pinem et al., 2018; TR 38.901, 2017).

This study aims to determine the most accurate propagation model of the existing propagation model. This study only used three outdoor to indoor propagation models, namely the 3GPP Model, WINNER+ Model, and COST231 Model (Castro et al., 2017). To determine which model is the most accurate, three validation formulations are used, namely Mean Error (ME), Root Mean Square Error (RMSE), and Standard Deviation Error (SDE) (Lofi & Houcine, 2017; Svistunov, 2017). Besides, the three propagation models were applied to the same research object, namely the lecture hall in the J14 Building of the University of North Sumatra, Indonesia. The

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study also aimed to determine the effect of the distance of transmitter and receiver that are too close to changes the path loss. This is considered necessary because overcrowding in urban areas causes limited land to establish transmitters. Therefore, in Indonesia, there are many transmitters placed on top of the building, especially in urban areas. The transmitter on top of the building cannot serve smoothly for receivers who are close to the building (Castro et al., 2017). This is because receivers who are too close to the transmitter get a small side lobe signal. However, the transmitter must also be able to provide internet service around the building. This study did not discuss the effect of changes in transmitter parameters on path loss (A. R. Abubar et al., 2020; P. M. Sihombing et al., 2020). This study only uses transmitter antennas with fixed parameters that have been determined by one of the telecommunication service providers in Indonesia.

Some previous studies have been researched empirical propagation models for the propagation of radio waves from outside into the building. The study (Rodriguez & Nguyen, 2016) aims to determine the influence of frequency, the number of walls, and types of buildings on the path loss. To find out the influence of frequency, it has been measured the path loss at the frequency of 0.8, 2.0, 3.5, 5,2, 10,0, 18,0, and 28 GHz in the same set of scenarios. To find out the influence of the number of walls in the building, measurements have been taken on shopping malls (few walls) and office buildings (many walls) using the same frequency. As for knowing the influence of the type of building materials, it has been done measurement of the path loss on old buildings and modern buildings. The old building is made of light construction material with thin walls that are commonly used in hot climates. Meanwhile, modern buildings are made of heavy construction materials with thick walls that are commonly used in cold climates. The study only used the 3GPP TR 38,900 Model which was later developed based on the measurement data that has been done. During the measurement process, the study used its antennas placed on the ground. So the measurement process does not represent the actual state. The study (Castro et al., 2017) aimed to determine the most accurate propagation model for predictions of path loss in lecture halls. The measurement of path loss is done at 3.5 GHz which is allocated for fifth-generation (5G) networks. The propagation models used are COST231, Winwer+, ITU-R, and 3GPP. Measurement of path loss is done using own antennas placed on the sidewalk. The study (K. Arana, 2020) aimed to determine the characteristics of path loss in multi-story buildings. Measurement of path loss has been performed at 6 GHz. Based on the results of the measurement has been obtained that the floor attenuation factor (FAF) path loss increases by an average of 2.93 dB per floor of the building. In the line of sight (LOS) state, the path loss exponent (PLE) is 1.02 dB and for the fifth floor, the average PLE is 1.59. Besides, the study has verified the accuracy of the Close-In Model (empirical model) using FAF values. Thus, it resulted in an increase in the accuracy of the model from an average error of 6.64 dB to 1.19 dB. The study (Lee, 2021) aimed to determine the characteristics of cluster-based empirical propagation at 32 GHz for 5G networks. Measurements were carried out on two office buildings. Based on the measurement results that there were a lot of reflections that bounce back and forth between windows increasing the number of clusters. Also, it is well known that multipath components (MPC) can be solved by the space-alternating generalized expectations-maximization algorithm and MPC clustering was performed by the K-power-means algorithm.

LITERATURE REVIEW

There are three types of propagation models, namely deterministic models, semi-deterministic models, and empirical models. Deterministic models require a complete description of the structure and style of barriers both outside and inside the building. Thus, deterministic models have the most accurate predictive results but are challenging to implement. Semi-deterministic models also require a complete description of the barrier between the transmitter antenna and the receiver antenna, but not as complete as the deterministic model. Semi-deterministic models also provide fairly accurate predictive results, but they are still quite challenging to implement (Degli-esposti et al., 2017). Empirical models do not require a complete description of the barrier, as in previous models. As such, empirical models are not accurate enough compared to previous models, but they are the easiest to implement. Besides, changes in structure, number, and type of barriers that occur so quickly both outside and in buildings, especially in urban and sub-urban areas, lead to empirical models being more reliable than other types of models. Some empirical models are the 3GPP Model, the WINNER+ Model, and the COST231 Model (Castro et al., 2017).

This study used empirical propagation models. The empirical propagation model was chosen because the research was conducted in sub-urban areas and within lecture halls. The empirical propagation models used in this study are the 3GPP Model, Winner+ Model, and COST231 Model. The propagation models were chosen because they were more up-to-date. The 3GPP model formula for the Line Of Sight (LOS) condition is shown in (1). The 3GPP models are applied in the range of 0.50 – 100 GHz at a radius of 10 – 5000 m (TR 38.901, 2017).

$$L_{3GPPL} = L_{OL3GPP} + L_{EW3GPP} + L_{In3GPP} + N(0, \sigma_P^2) \quad (1)$$

Besides, the model has also been widely used as a reference for research related to propagation models (Castro et al., 2017; Degli-esposti et al., 2017; Rodriguez & Nguyen, 2016). L_{3GPPL} is the total path loss in the 3GPP model (dB). L_{OL3GPP} is the path loss outside the building in the 3GPP model (dB). L_{EW3GPP} is the path loss due to signal penetrating the outer wall of the building (penetration losses) in the 3GPP model (dB). L_{In3GPP} is the path losses inside the building in the 3GPP model (dB). N (0, σ_P^2) is the path losses determined based on the multiplication result between the number of walls (N) penetrated by the signal and the standard deviation (σ_p) of wall penetration losses (dB) (TR 38.901, 2017).

The Winner+ model formula for the LOS condition is shown in (2). The Winner+ models are applied in the range of 0.45 – 6.0 GHz at a radius of 10 – 5000 m (Castro et al., 2017).

$$L_{WL} = L_{OLW} + 21{,}04 + 14.(1 - 1{,}8.log_{10}(f_c)) + L_{InW} \qquad (2)$$

Besides, the model has also been widely used as a reference for research related to propagation models (Castro et al., 2017; Kristem et al., 2017; MacCartney & Rappaport, 2017). L_{WL} is the total path losses in the Winner+ Model (dB). L_{OLW} is the path losses of outside the building in Winner+ Model (dB). f_c is a frequency carrier (GHz). L_{InW} is the path losses inside the building in the Winner+ Model (Castro et al., 2017).

The COST231 model formula for the LOS condition is shown in (3). The COST231 models are applied in the range of 0.9 – 1.8 GHz at a radius of up to 500 m (Castro et al., 2017).

$$L_{CL} = 32{,}4 + 20.log_{10}(f_c) + 20.log_{10}(d_{out} + d_{in}) + L_{EWC} + max(\Gamma_1, \Gamma_2) \qquad (3)$$

Besides, the model has also been widely used as a reference for research related to propagation models (Castro et al., 2017; Degli-esposti et al., 2017). L_{CL} is the total path losses in the COST231 model (dB). L_{EWC} is penetration losses in the COST231 model (dB). Max (Γ_1, Γ_2) is determined by the distance, angle, and the number of walls penetrated by signals in the building (dB). d_{out} is the distance between the transmitter antenna and a point on the outermost wall of the building closest to the receiver antenna (m). d_{in} is the distance between a point on the outer wall of the building against the receiver antenna, as illustrated in Fig. 1. h_{Tx} is the total height of the transmitter antenna (m). h_g is the height of the building (m). h_{bs} is the high of the transmitter antenna (m). h_{Rx} is the antenna height receiver (m). d2D – out is the distance between the transmitter antenna and the receiver antenna based on the axis – x (m). θ is the elevation angle between the building and the signal is coming (degrees).

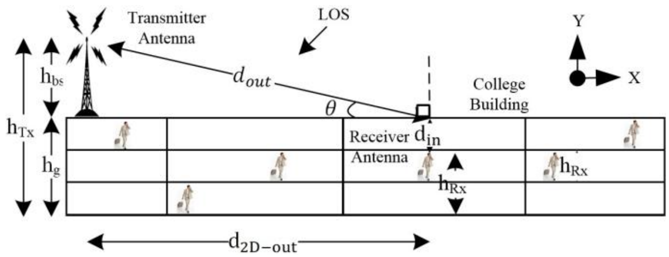

Fig.1. COST231 Model Distance Variable Explanation Illustration

METHOD

This section includes the specifications of research objects, measurement methods, and methods of determining the most accurate propagation models.

Specifications of research objects

This research was conducted at the Faculty of Engineering Building at the University of North Sumatra. The building is composed of four interconnected buildings, namely J14 Building, J15 Building, J16 Building, and J17 Building as shown in Fig. 2. The buildings are made of concrete equipped with windows on each outside wall. The windows are made of thin glass that has a uniform width on each window, which is 60 cm. This study only focused on the J14 Building as the object of research. The exterior view of the building is shown in Fig. 3. While the layout of the building is shown in Fig. 4.

Around J14 Building there are some shady trees with a height of no more than 20 m. Similar to other buildings, J14 Building is composed of three floors where the distance between floors is 4 m. There are many rooms in the building, but this study focuses only on lecture rooms on the first floor. There are three lecture halls on the first floor which in this study were named College Room 1, College Room 2, and College Room 3 as shown in Fig. 4. In each lecture room is also equipped with a uniform-sized window as shown in Fig. 5. The windows are made of

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thin glass mounted on the wall of the room leading to the corridor and wall of the room leading to the outside of the building. The size of the window in the room is 60 cm.

Fig.2. the Top View of J14 Building (Google Earth, retrieved December 02, 2021, at 3.45 pm)

Fig.3. the Side View of J14 Building

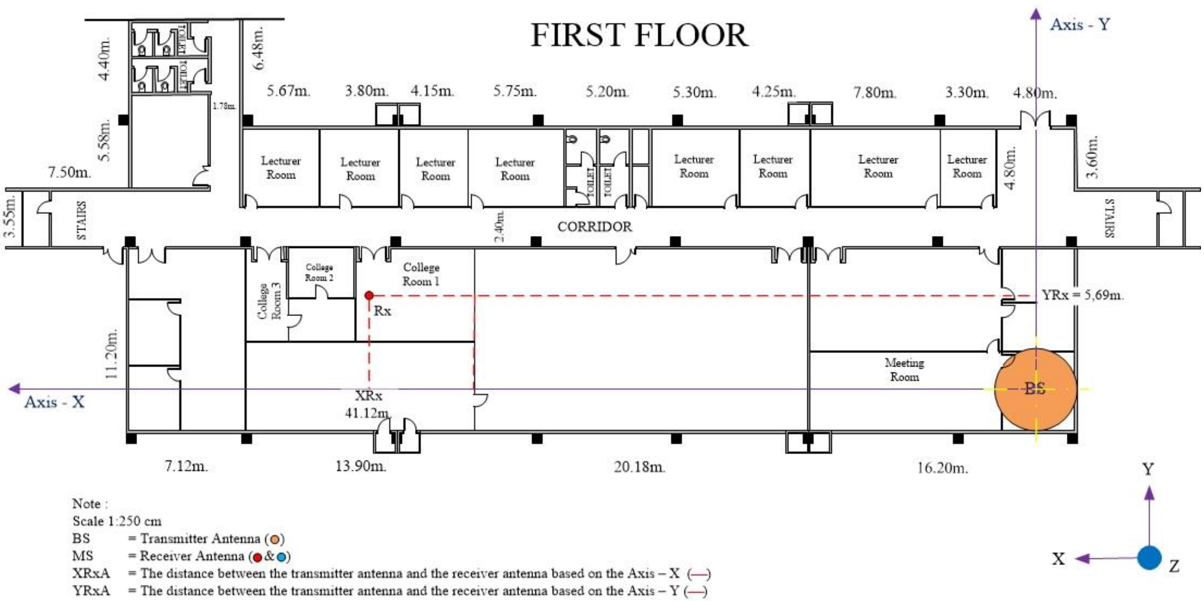

Fig.4. First Floor J14 Building Floor Plan and Projection of Transmitter Antenna

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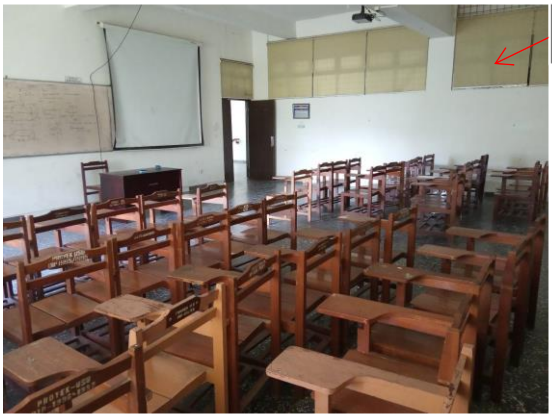

Fig.5. College Room of J14 Building on First Floor

The height of the first floor against the ground floor is 1 m. The specifications of the building's material are shown in Table 1. An illustration of the position of the transmitter antenna and J14 Building is shown in Fig. 1.

Table 1
J14 Building Specification

Specifications	Type of Material	Thickness (cm)
Roof	Concrete	30
Floor	Concrete	30
Wall	Brick	17
Window	Glass	1

A trigonometric approach is used to determine the distance between the transmitter and the receiver. Based on Fig. 4, the distance between the transmitter and the receiver can be obtained using (4).

$$d = \sqrt{{X_R}^2 + {Y_R}^2} \quad (4)$$

Antenna Specification

Transmitter and receiver specifications are shown in Table 2 and Table 3, respectively. This study used a transmitter antenna belonging to one of the telecommunication service providers in Indonesia. The specifications of the transmitter antenna are shown in Table 2. The transmitter antenna is located on top of the J14 Building, as shown in Fig. 6. Simultaneously, the receiver antenna used is an antenna embedded in a mobile communication device (Sony Ericsson W995 brand).

Table 2
Transmitter Antenna Specification (Tongyu communication, 2007)

Parameters	Transmitter Antenna Specification	
	1800 MHz	2100 MHz
Brand &Type	Tongyu TDQ-182020DE-65P (sectoral)	Tongyu TDQ-182020DE-65P (sectoral)
Frekuensi	1,795 MHz	2,045 MHz
Daya Pancar (EIRP)	66.8 dBm	66 dBm
Gain	19 dBi	19 dBi
Azimuth	40^0	40^0
The Total Antenna Height (h_{BS})	22.8 m	22.8 m
Antenna Height (h_{bs})	10 m	10 m
Building Height (h_g)	12 m	12 m

Table 3
Receiver Antenna Specification (Sony Ericsson Mobile Communication AB, 2009)

Parameters	Receiver Antenna Specification for 1800 MHz and 2100 MHz
Brand	Sony Ericsson W995
Type	*Omnidirectional*
Feeder Loss	0 dB
Gain	1.5 dB
Height (h_{ms})	1.5 meter

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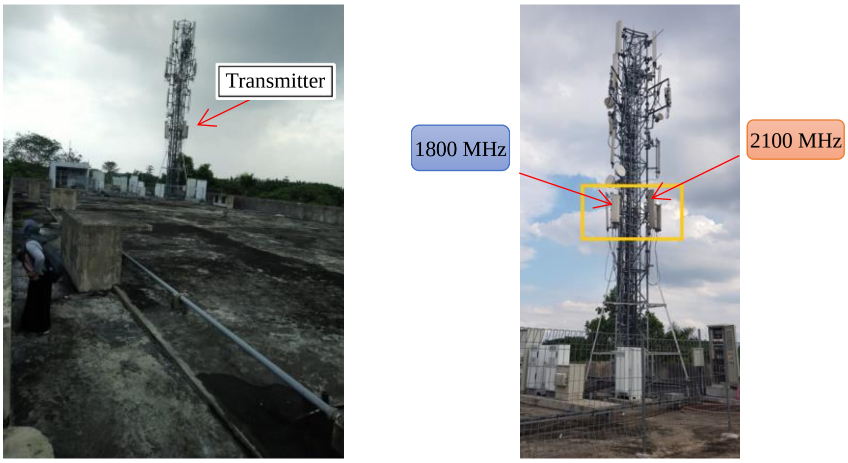

(a) (b)

Fig.6. (a) Transmitter position on the roof of Building J14 (b) Transmitter Position for each frequency

Measurement Method

Measurement of received signal level and path loss was carried out by walking using a set of drive test tools, as shown in Fig. 7 and Fig. 8. The device consists of two Sony Ericsson W995 mobile phones, a GPS dongle, a Transmission Evaluation and Monitoring System (TEMS) Investigation 10.0.5 software, a laptop along with data cables and connectors. Those mobile phones were receivers. Receiver 1 and Receiver 2 were used to measure signals at 1800 MHz and 2100 MHz respectively. TEMS Investigation 10.0.5 software is used to record and process signals in the form of receiving signal levels and loss paths.

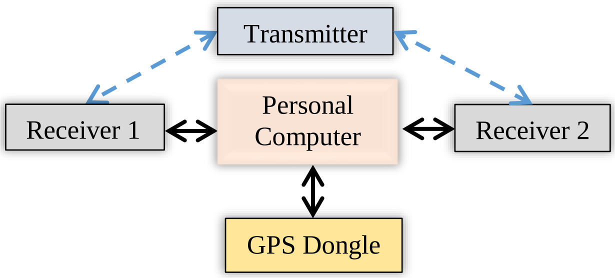

Fig.7. Drive Test System Suite

Fig.8. Drive Test Tools

The process of measuring path loss is done as follows. First, TEMS Investigation Software 10.0.5 and Sony Ericsson W995 driver were installed into the laptop Second, input the transmitter's cell id and lock the receiver so that it does not experience handover. Third, measure the signal in the middle of the designated lecture hall on foot as shown in Fig. 4. Receiver 1 and Receiver 2 will detect transmitter signals at 1800 MHz and 2100MHz respectively. Furthermore, the signal will be recorded and processed by TEMS Investigation 10.0.5 software in the computer and converted into the path loss values. In this study, 142 signal measurement links were conducted in the designated lecture hall. All of these measurement links consist of 71 signal measurements at 1800 MHz and 71 signal measurements at 2100 MHz.

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Methods of Determining the Most Accurate Propagation Models

There are two ways to determine the most accurate propagation model in this study. The first way is to compare the graph of the measurement results with the calculation results using each propagation model formula. The second way is to compare some error validation of each propagation model. Currently, there are many error validations, but this study only uses three error validations. The three validation errors are ME, SDE, and RMSE. The three validation errors are determined using (5), (6), and (7) (Svistunov, 2017; Yu et al., 2017).

$$ME = \frac{1}{n} . \sum_{i=1}^{n} |L_{meas.A} - L_{calc.A}| \quad (5)$$

$$ESD = \sqrt{\frac{1}{n} . \sum_{i=1}^{n} (|L_{meas.A} - L_{calc.A}| - ME)^2} \quad (6)$$

$$RMSE = \sqrt{\frac{1}{n} . \sum_{i=1}^{n} |L_{meas.A} - L_{calc.A}|^2} \quad (7)$$

The n is the number of samples measuring the strength of radio wave signals. LmeasA is the loss of radio wave trajectory at point A of the measurement results (dB). Lcalc.A is the loss of radio wave trajectory at point A of the calculation result using the propagation model (dB) (Svistunov, 2017; Yu et al., 2017).

RESULT

This section compares path loss predictions based on the calculation results using each propagation model formulas. College Room 1, College Room 2, and College Room 3 are the objects of research in this study.

Comparison of Propagation Models in College Room 1

In College Room 1 had been done 66 measurement links of path loss at 1800 MHz and 2100 MHz. In the lecture hall had also been done calculation or prediction of path loss using the propagation model that has been determined. The results of the measurement and calculation of the path loss are shown in Fig. 9 and Fig. 10. Fig. 9 and Fig. 10 are path loss curves in College Room 1 at 1800 MHz and 2100 MHz respectively. Table 4 is a comparison of the validation error values of each propagation model in College Room 1 at 1800 MHz and 2100 MHz respectively.

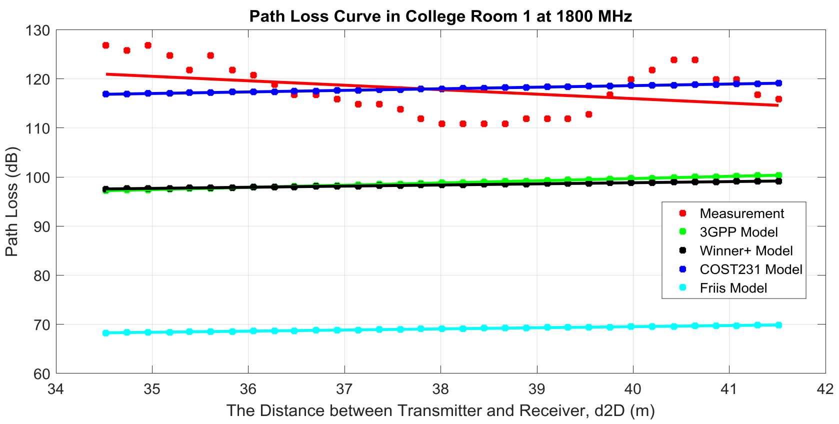

Fig.9. Path Loss Curve in College Room 1 at 1800 MHz

Table 4
Comparison of ME, ESD, and RMSE of each Propagation Model in College Room 1

Model	1800 MHz			2100 MHz		
	ME (dB)	ESD (dB)	RMSE (dB)	ME (dB)	ESD (dB)	RMSE (dB)
3GPP	18.92	5.46	19.69	21.37	2.29	21.49
Winner+	19.33	5.25	20.03	23.21	1.99	23.29
COST231	4.70	2.75	5.44	2.63	1.50	3.03

Based on Fig. 9 and Fig. 10, the COST231 Model curve is closest to the measurement result curve compared to other propagation models used. That happens for both frequencies. Besides, Based on Table 4, the ME, ESD,

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and RMSE values of the COST231 model have the least value than other propagation models. The validation error values are the least for 1800 MHz and 2100 MHz. Thus, this shows that in College Room 1, the COST231 Model is most accurate compared to other predetermined propagation models.

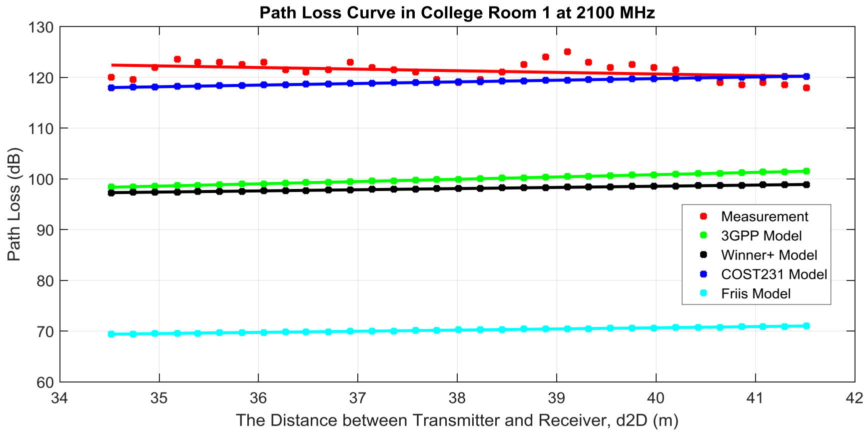

Fig.10. Path Loss Curve in College Room 1 at 2100 MHz

Comparison of Propagation Models in College Room 2

In College Room 2 had been done 36 measurement links of path loss at 1800 MHz and 2100 MHz. Fig. 11 and Fig. 12 are path loss curves in College Room 2 at 1800 MHz and 2100 MHz respectively. Table 5 is a comparison of the validation error values of each propagation model in College Room 2 at 1800 MHz and 2100 MHz respectively.

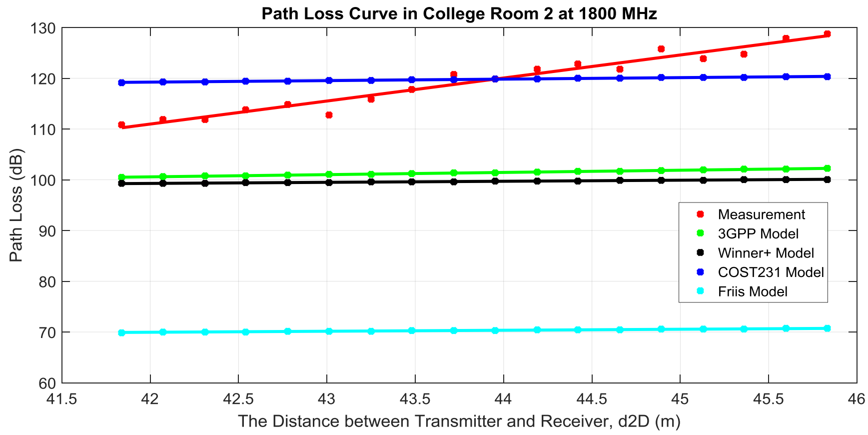

Fig.11. Path Loss Curve in College Room 2 at 1800 MHz

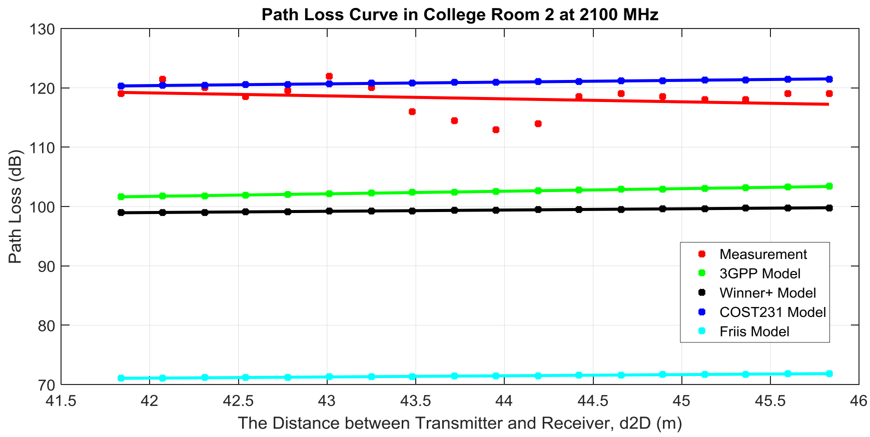

Fig.12. Path Loss Curve in College Room 2 at 2100 MHz

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Based on Fig. 11 and Fig. 12, the COST231 Model curve is closest to the measurement result curve compared to other propagation models used. Besides, based on Table 5, the ME, ESD, and RMSE values of the COST231 model have the least value than other propagation models used. Thus, this shows that in College Room 2, the COST231 Model is most accurate compared to other predetermined propagation models.

Table 5
Comparison of ME, ESD, and RMSE of each Propagation Model in College Room 2

Model	1800 MHz			2100 MHz		
	ME (dB)	ESD (dB)	RMSE (dB)	ME (dB)	ESD (dB)	RMSE (dB)
3GPP	17.32	5.70	18.23	15.72	2.54	15.92
Winner+	19.02	5.95	19.93	18.85	2.43	19.01
COST231	4.64	2.60	5.32	2.96	2.14	3.65

Comparison of Propagation Models in College Room 3

In College Room 3 had been done 40 measurement links of path loss at 1800 MHz and 2100 MHz. Fig. 13 and Fig. 14 are path loss curves in College Room 3 at 1800 MHz and 2100 MHz respectively. Table 6 is a comparison of the validation error values of each propagation model in College Room 3 at 1800 MHz and 2100 MHz respectively.

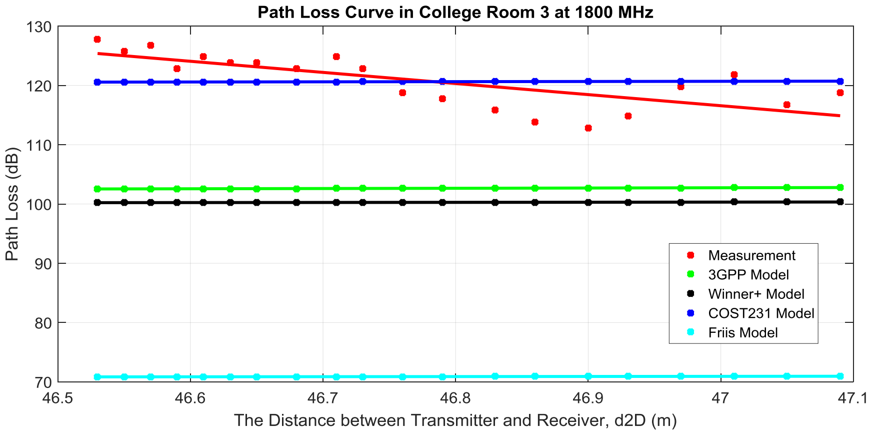

Fig.13. Path Loss Curve in College Room 3 at 1800 MHz

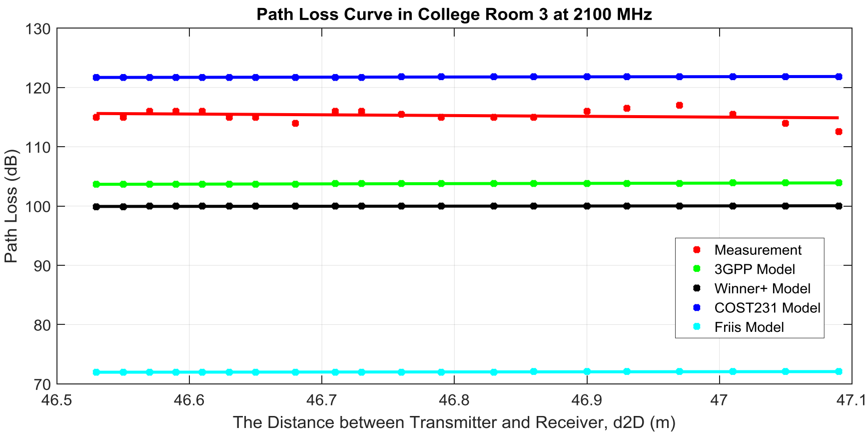

Fig.14. Path Loss Curve in College Room 3 at 2100 MHz

Table 6
Comparison of ME, ESD, and RMSE of each Propagation Model in College Room 3

Model	1800 MHz			MHz		
	ME (dB)	ESD (dB)	RMSE (dB)	ME (dB)	ESD (dB)	RMSE (dB)
3GPP	17.61	4.76	18.24	11.53	1.00	11.57
Winner+	19.97	4.73	20.53	15.32	1.00	15.35
COST231	3.90	2.04	4.40	6.46	0.99	6.54

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Based on Fig. 13 and Fig. 14, the COST231 model curve is closest to the measurement result curve compared to other propagation models. That happens for both frequencies. Also, based on Table 6, the value of ME, ESD, and RMSE model COST231 is the least compared to other propagation models used. Thus, this shows that in College Room 3, the COST231 Model is most accurate compared to other predetermined propagation models.

Comparison of Propagation Models in All of College Room

In College Room 1, College Room 2, and College Room 3 had been done 142 measurement links of path loss at 1800 MHz and 2100 MHz. Fig. 15 and Fig. 16 are path loss curves in all college rooms at 1800 MHz and 2100 MHz respectively. Table 7 is a comparison of the validation error values of each propagation model in all college rooms at 1800 MHz and 2100 MHz respectively.

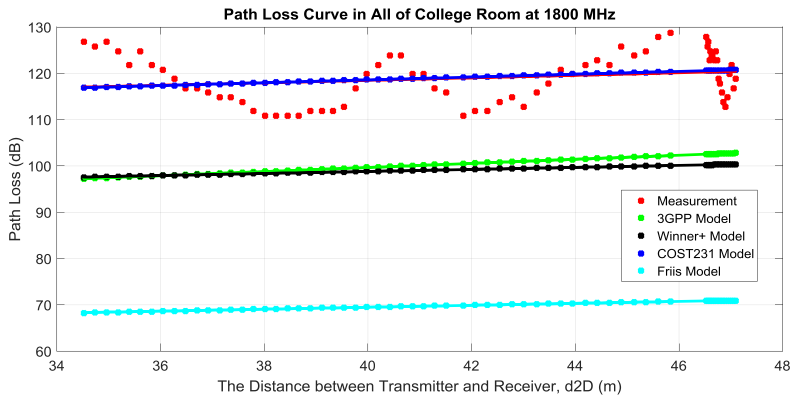

Fig.15. Path Loss Curve in All of College Room at 1800 MHz

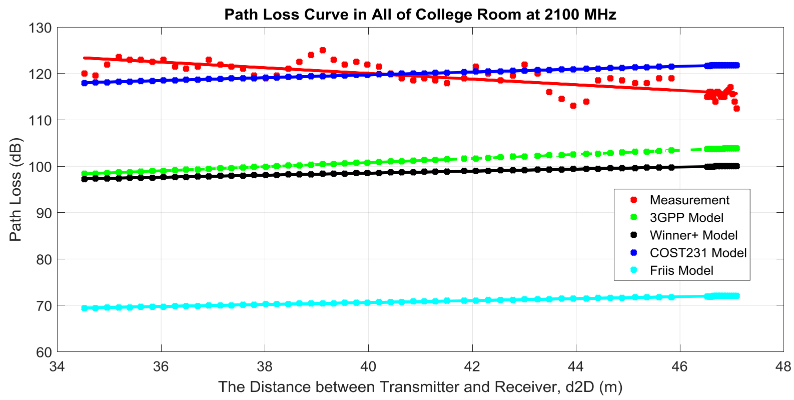

Fig.16. Path Loss Curve in All of College Room at 2100 MHz

Table 7
Comparison of ME, ESD, and RMSE of each Propagation Model in All of College Room

Model	1800 MHz			2100 MHz		
	ME (dB)	ESD (dB)	RMSE (dB)	ME (dB)	ESD (dB)	RMSE (dB)
3GPP	18.50	5.18	19.21	17.16	4.69	17.79
Winner+	19.79	5.14	20.44	19.88	3.86	20.25
COST231	4.46	2.55	5.14	3.80	2.30	4.44

Based on Fig. 15 and Fig. 16, the COST231 model curve is closest to the measurement result curve compared to other propagation models. That happens for both frequencies. Also, based on Table 7, the value of ME, ESD, and RMSE model COST231 is the least compared to other propagation models used. Thus, this shows that in all college rooms, the COST231 Model is most accurate compared to other predetermined propagation models.

DISCUSSIONS

Based on Fig. 9 on the measurement result curve, there was some decrease in path loss at a distance of between 35.5 m – 38.5 m and some increase in path loss between 38.5 m – 40.5. Based on Fig. 4, this was because the receiver moves near and away from the middle College Room 1. Thus, the receiver gets more reflected signals than wall penetrating signals. Therefore, the change in path loss is more influenced by the reflected signal obtained than the distance between the transmitter and the receiver in this state.

Based on Fig. 10 on the measurement result curve, there was no significant decrease and increase in path loss due to changes in receiver position or distance between receiver and transmitter. Based on Fig. 6, this was because the transmitter was not designed to transmit signals to the space of College Room 1. Thus, the signal received by the receiver is the sidelobe signal.

Based on Fig. 11 on the measurement result curve, there was a significant increase in path loss. Based on Fig. 4, this was because the door's position in College Room 2 did not lead to the corridor as the door's position in College Room 1 before. Besides, in College Room 2, there was no window. Thus, the received signal mostly comes from penetrating the wall and not reflecting or penetrating glass windows.

Based on Fig. 12 on the measurement result curve, a slight decrease in path loss was comparable to the increased distance between receiver and transmitter. Based on Fig. 4 and Fig. 6, that caused by the receiver obtained a larger side lobe signal relative to the increased distance between the receiver and the transmitter.

Based on Fig. 13, there was a significant decrease in path losses, although there was only a slight increase in the transmitter and receiver distance. Based on Fig. 4, this was because the receiver in College Room 3 moved close to the door. Thus, the receiver got more reflected signals from the corridor.

Based on Fig. 14, there was no change in the path losses in College Room 3 even though, based on Fig. 6, the receiver moved close to the door. Based on Fig. 4, this was because the transmitter for 2100 MHz did not emit signals towards the College Lecture 3. Thus, the receiver only got a side lobe signal. However, the path loss in College Room 3 for 2100 MHz was the least compared to College Room 1 and College Room 2.

CONCLUSION

Based on the results of the discussion obtained some conclusions from the results of this study. Some of these conclusions, namely the COST231 model is the most accurate model for predicting outdoor to indoor path loss at 1800 MHz and 2100 MHz in J14 Building. Receivers that are too close to the transmitter (< 47 m) will get a side lobe of the transmitter so that the received signal power level is inadequate. Increased path losses are more affected by wall resistance than the distance between transmitter and receiver. The receiver which gets signals from reflections has fewer path losses than the receiver which gets signals from wall penetrating. The side lobe signal received by the receiver affects the path loss more than the distance between the receiver and transmitter. The increased signal frequency has almost no effect on path loss.

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