

Improvement of Lafortune-Lacrous Indoor Propagation Model at 1900 MHz Band

Ali Bendallah*, Ivica Kostanic

College of Engineering, Florida Institute of Technology, USA

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Abstract A new improvement approach to Lafortune-Lecours indoor propagation model is presented. Taking into consideration; different types of walls that have been not considered in the model. The concrete and brick walls cause considerable severe signal deterioration when they obstruct the transmission path of the signal. Improvement of the above mentioned model is achieved by computing the path loss through those kinds of obstructions by adding some parameters and terms to the existing model.

Keywords Building Layout, Lafortune-Lecours Model, Prediction of Propagation, Signal Deterioration, Total Path Loss, Transmission Phenomena, and Correction Factor

1. Introduction

Many studies to predict propagation inside building have been conducted and the reason behind that is to predict the propagation behavior inside buildings so the optimum location of the base stations can be chosen to ensure maximum capacity and minimum co-channel interference. [1]-[4]. The prediction of propagation behavior inside building becomes more difficult because of propagation phenomena such as, reflection, diffraction and scattering, for instance. The signals propagating through walls suffer significantly higher losses than in free space. The existence of different obstruction with different materials will provide different propagation paths.

For same-floor propagation measurements, the attenuation factor was found to be 2.4 dB for concrete or brick walls which conforms to the result obtained in [2], which will be included as additional term in Lafortune-Lecours model(LL model) as improvement contribution to this model. The standard deviation between the measured and predicted path loss is with average error of 8.66 dB and standard deviation of 6.15dB in case of not taking into consideration the concrete and brick walls whilst the average error of 0.38 dB and standard deviation of 5.95 dB in case of concrete and brick walls. The presence of any material in the path of transmission between the transmitter and receiver severely

affect the propagation characteristics of any wave signal. It is very important to understand the impact of the physical surrounding on the propagation.

Several studies tried to measure the propagation inside building and then model it statistically [5]-[9].

In this paper, we present statistical analyses of 1900 MHz band measurements inside a three-story building. Also some modification on Lafortune-Lecours propagation model were made by taking concrete and brick walls into consideration. By adding a new correction factor; number of concrete walls is counted and then plugged in the modified Lafortune-Lecours equation for computing the path loss through walls L_{OB} .

$$L_{OB} = 3.7 - (1.5n_s) - 10.7\log_{10}(d) \quad (1)$$

where

L_{OB} Path loss through walls.

n_s Number of soft walls

d Distance between the transmitter and receiver.

The path loss through brick or concrete walls has been found to be equal to 2.4 dB per concrete or brick wall, this factor is to be included in the equation (1) to consider the impact of brick walls, equation (2) to consider to the impact of concrete or brick walls

$$L_{OB} = 3.7 - (1.5n_s + 2.4n_c) - 10.7\log_{10}(d) \quad (2)$$

n_c : Number of concrete walls.

The term $2.4n_c$ is added as a correction factor to consider the brick walls which had not been considered in Lafortune-Lacrous model.

The measurement of the signal strength is conducted in three floors of Olin engineering building. The total path loss is computed as the free path loss and additional path losses caused by the obstructions between the transmitter and receiver.

The modified LL model in this paper is used to predict the path loss at the measurement locations. The difference between the predicted and measured values of the path loss is implemented as a tool to develop path loss prediction error and then determining the cause of the deviation. By knowing the deviation in the measurements and predictions will help determining the main cause of the signal deterioration and then finding the optimal solution.

2. Modified Lafortune-Lacrous Indoor propagation Model and Methods

Lafortune and Lecours [3] conducted indoor propagation losses modeling in two 50,000 square meter office buildings at 900 MHz. The continuous wave emission was at 917 MHz. A synthesized signal source was used as transmitter with power of 10 dBm for most measurements and 19 dBm for measurements between two floors or more. The transmit antenna was kept fixed at a height of 1.7 or 2.5 m and the receiving antenna was moved, at a height of about 1.7 m. The propagation losses in free space are a function of frequency used, antenna gain and the separation between transmitter and receiver. Lafortune and Lecours introduced two parameters LOB and GRM to represent the losses due to obstacles or the gain caused by multiple reflections.

The propagation loss in free space is a function of transmit power, antenna gain, frequency, and distance as follows

$$L_{FS} = 20 \log_{10}(f)[MHz] + 20 \log_{10}(d)[m] + 32.44 \quad (3)$$

And the received signal power P_R is given by

$$P_R = P_T + G_T + G_R + L_{FS} + L_{OB} + G_{RM} \quad (4)$$

where

- P_R, P_T the received and transmitted powers,
- G_R, G_T the receiver and transmitter antenna gains,
- L_{OB} Loss due to obstacles,
- G_{RM} Gain due to reflections.

and the free space is calculated L_F as below

$$L_{FS} = 20 \log_{10}(\lambda/4\pi d) \quad (5)$$

Where

λ : wave length, d : distance.

Lafortune and Lecours conducted measurements inside building to evaluate or model the loss due to obstacles (L_{OB}) and gain due to reflections (G_{RM}).

To measure the losses through walls and to isolate the transmission phenomenon, the sites to be measured have been chosen where the reflection and diffraction phenomena were considered negligible; in the sites where there was no corridor parallel to the line joining transmitter and receiver [1].

The distance between the transmitter and first wall d' is also taken into consideration. If the distance d' is less than 4 m, there is no change and equation (2) is used.

In case of $d' > 4$ m, the following extra expression is added to equation (2) to compute the path loss through walls.

$$+ 0 \quad \text{if } d' < 4 \text{ m} \quad (6)$$

$$-7.8 + 15.3 \log_{10}(d') \quad \text{if } d' > 4 \text{ m} \quad (7)$$

Another phenomenon; where the signal encounters an obstacle which is called reflection, is studied. The reflection can bring higher signal level than in the free space. This effect has been observed in corridors and in large rooms

when there is line of sight transmission.

The effect of windows, window screen and doors (when they are open) is studied. Also, Lafortune-Lecours studied the effect of the low-level office furniture and found that it is not a significant with the antenna heights considered.

The effect of reflection associated with the existence of the obstacles is taken into consideration. It has been found that in some configurations, that significantly higher signal level that would be in the case with free space propagation. The reflection effect has been clearly observed in corridors and in large rooms when there is free-obstacle transmission path between the transmitter and receiver.

The accuracy of measurements and the resultant model; which describes the path loss inside buildings, depends on the building materials and the architecture configuration of the building. Those parameters limit the accuracy of any model to be used to predict the signal attenuation inside buildings.

It has been found that in Lafortune-Lecours model, 68% of the measurements fall within ± 2 dB of the estimated level and a standard deviation of lower than 3 dB [3].

The method used required a fairly knowledge of the building architecture and configuration and identifying the transmission phenomena such as, diffraction, reflection and propagation losses. According to the model, it has been found that the influence of the different building materials and the variability in architectural configuration of the building limit the accuracy of any model and making it general to all buildings. There will be a spread between the actual and predicted measurements of the path loss inside buildings.

It had been noted that the accuracy of the measurements will decrease with the distance and the existence of obstacles between the transmitter and receiver, which corresponds to increasing uncertainty and diversity of the buildings layout, architecture, geometry, type of furniture and the building layout.

3. Experiment Environment

Path loss measurements for this study are collected in a three-story building at the campus of Florida Tech in the third floor. The transmitter operating frequency is 1925 MHz with a transmit power of 6 dBm. The receiver and the transmitter are located on the same floor of OLIN building. The floor plan of the building is depicted in Fig.1.

There are 29 offices, 11 labs, one elevator, two emergency exit, stairs and hallways. The offices and labs have metal stud walls while the walls of emergency exits and elevator are from concrete white brick. The height of ceiling is 9' 2" covered with acoustical ceiling pressed fiber tiles. All the measurements have been taken in 20,770 square foot floor in the Olin engineering building.

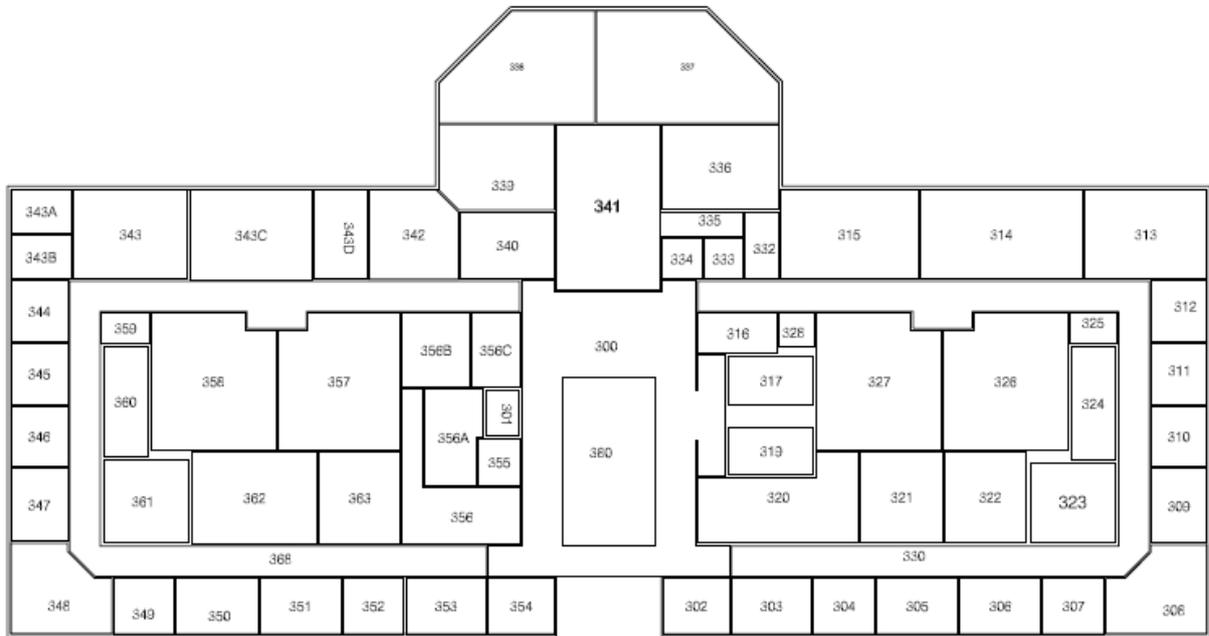


Figure 1. OLIN engineering third floor plan

4. Measurements Procedure

The measurements are collected in 1900 MHz band inside OLIN Engineering building and Table 1 shows the parameters associated with the measurements scenarios.

Table 1. Parameters associated with the measurement scenarios

Parameter	Values
Operating frequency	1925 MHz
Transmit antenna height	1.47 m
Transmitting power	6 dBm
Transmit antenna gain	6 dB
Cable and connector losses	0.7 dB
Receive antenna height	0.72 m
Receive antenna gain including cable losses	5 dB
Noise Figure	2 dB

5. Experiment Scenarios

In-building RF propagation prediction is the first step in modeling the propagation behavior inside the building. There are many factors that impact the wireless propagation, such as the structure of the building, the materials inside it, and the associated factors which lead to more attenuation and cause loss of signal strength. Spectrum clearing conducted for 12 hours. The average reading value was -130.8 dBm with standard deviation of 2.66 dB.

The experimental data were collected inside OLIN engineering building, Florida Tech (FIT) during the day and night time. The measurements conducted for this work are collected in three-story building of FIT Melbourne, FL, USA. The measurement points are 8 feet apart in the hallways inside the building.

Table I depicts the parameters associated with the measurement procedures. The measurements are conducted

over a period of couple of weeks.

The signal strength measured is averaged at each point to eliminate the fast fading that is due to motion of the environment that is surrounding both the transmitter and the receiver. The averaging time is three minutes.

In this measurement campaign, the transmitter is kept fixed while the receiver is moving to measure the signal strength at each point. At transmission side, the antenna was an omni-directional type with 6 dBi gain and vertical polarization.

At the reception side, data collection process is divided into two campaigns. First measurement campaign was performed to collect the in the signal strength data. The transmitter is mounted in the corner of the building with antenna height of 1.47 m. The measurement equipment was installed on a cart that can be moved. The omni-directional antenna was attached to a plastic mast.

In all these scenarios, the presence of concrete and brick walls were not taken into consideration as to validate the model proposed by Lafortune as it is without any modifications or tuning.

In the second measurement campaign, the transmitter is mounted in the middle of the building, and the signal strength is measured all through the hallways.

To improve the accuracy of Lafortune-Lecours model experimentally, two measurement scenarios are carried out. The path loss is computed with and without taking into consideration the concrete walls in each floor.

The investigation process considers two experimental scenarios. The scenarios are described as follows.

5.1. First Scenario: Transmitter in the Corner

The measurement of signal strength is conducted in the

third floor, where the transmitter is mounted in the building corner as depicted in Fig.2. The receiver is recording the signal strength in the hallway inside the building with total of 61 measurement points of 8 foot apart between each consecutive point.

In this measurements scenario, all measurements points have no line of sight. Before being measured, the signal has to pass through at least one obstruction.

The signal strength is measured and averaged at each measurement point around the hallway inside the building. Fig.2 predicts the signal strength measurements.

5.2. Second Scenario: Transmitter in the Middle of the Building

In this scenario, the transmitter is mounted in the middle of the building. Some measurements have a clear line of sight to the transmitter. Also, for the measurements points that do not have LOS, the signal is propagating through spectral reflections from the floor, ceiling and the building walls. The outline of the measurements in the second scenario is depicted in Fig.3.

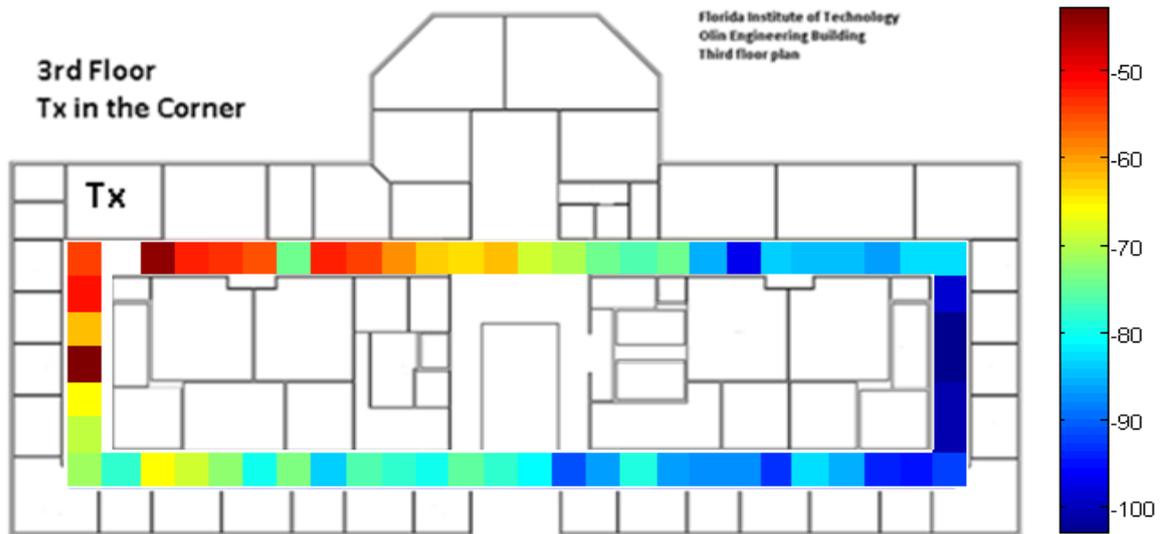


Figure 2. Signal strength measurements (First scenario)

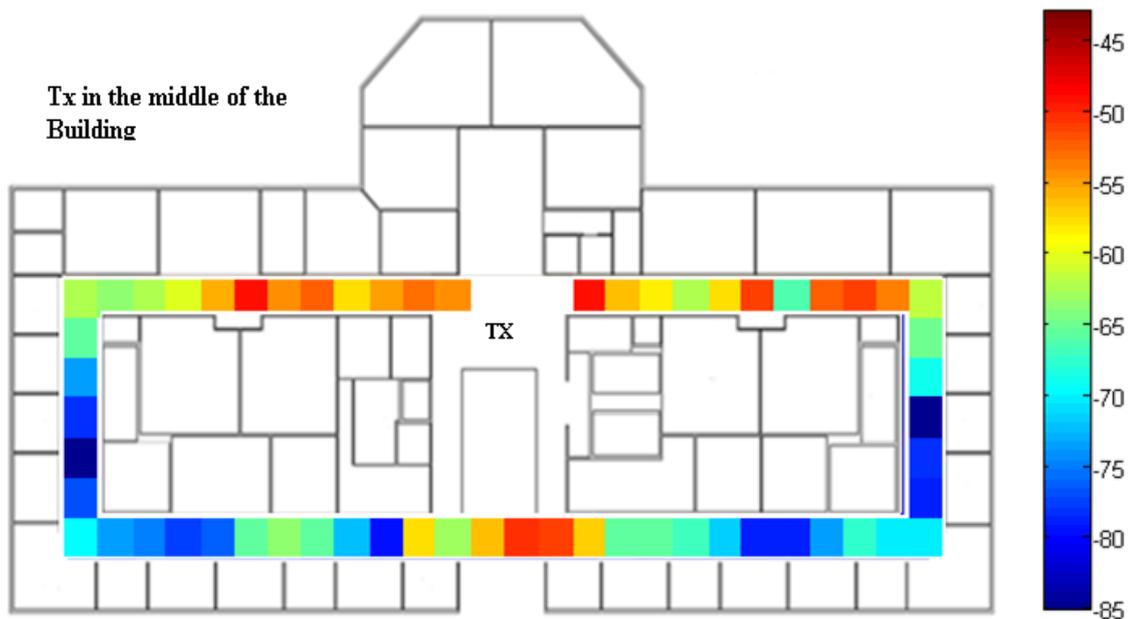


Figure 3. Signal strength measurements (second scenario)

6. Investigation of the Accuracy of Lafortune-Lacrous Indoor Propagation Model

Lafortune and Lacrous conducted measurements of signal strength at 900 MHz at two story building and came up with a model that computes the path loss inside buildings. The next step to be done is to investigate the validity of this model in Florida Tech. at OLIN Engineering building.

6.1. Results and Analysis of Experimental Validation Process

The signal strength inside the building is measured at each point through the hallway inside OLIN Engineering building at 1900 MHz. The signal strength is decreasing as the distance increases that can be clearly show in figure4 & Figure5. The impact of the walls is another factor that affects the propagation inside the building.

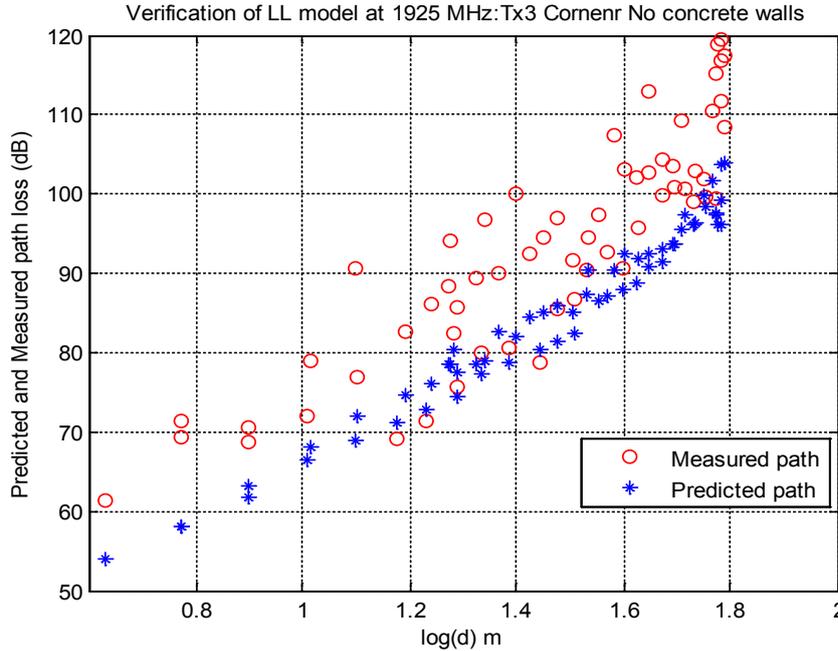


Figure 4. Verification of Lafortune model (sceanriol No concrete walls)

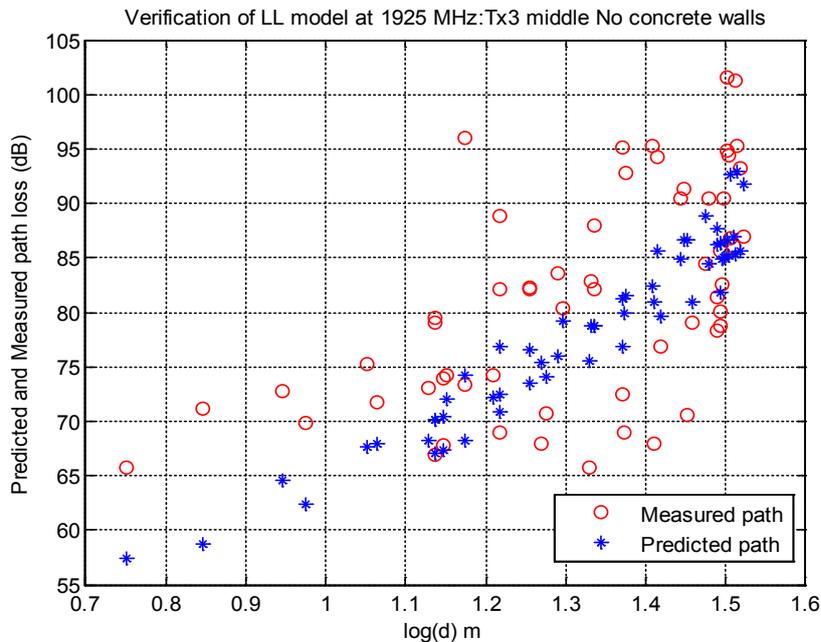


Figure 5. Verification of Lafortune model (sceanrio2 No concrete walls)

The error histogram Fig.6 shows the average error between the measured and predicted values of the path loss inside the building. The average error is 8.66 dB with standard deviation of 6.15 dB. The average error is high. The concrete walls were considered.

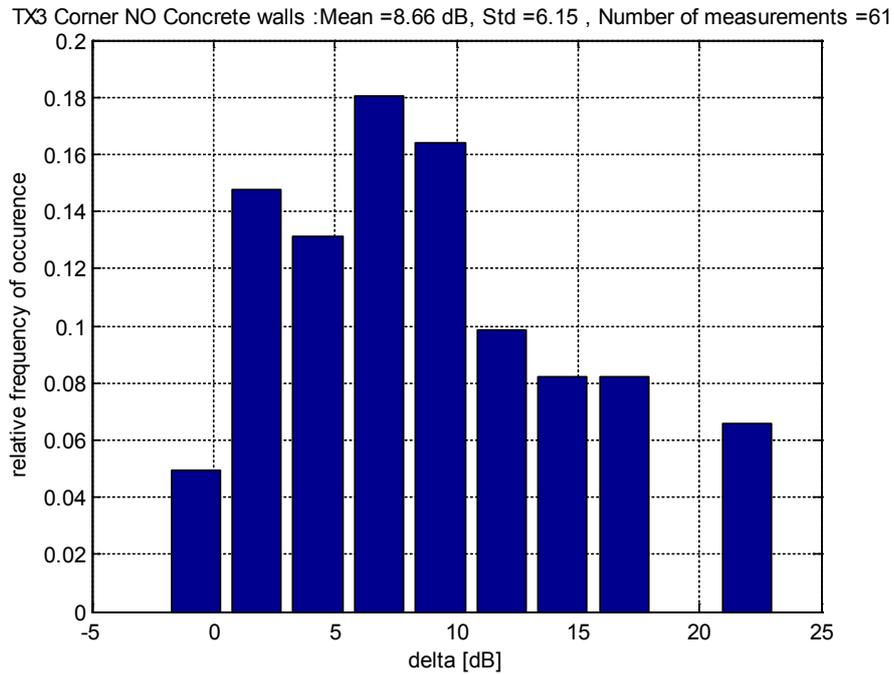


Figure 6. Error Histogram (Scenario 1 No concrete walls)

The error average of the difference between the measured and predicted values of the path loss in the second scenario is 3.03 dB with standard deviation of 7.78 dB.

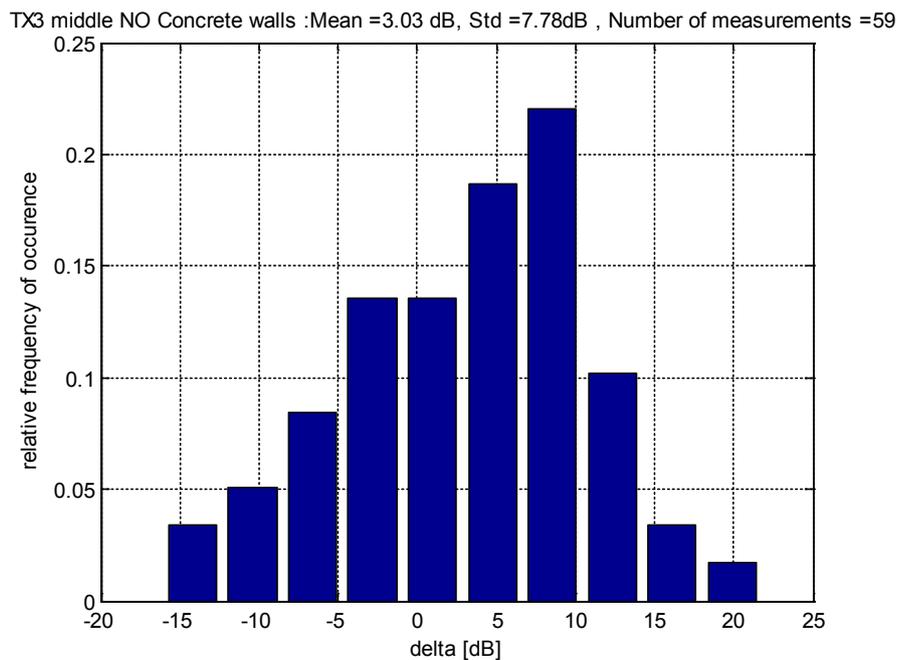


Figure 7. Error histogram (Scenario 2 No concrete walls)

The difference between the measured and predicted values of the path loss is in some cases are very high, and the model failed to show a good prediction. Table 2 & 3 depict some values of average error where the model did not show good prediction.

Table 2. Measured and predicted path loss (scenario1)

Rx(dBm)	No of walls	Measured values of path loss (dB)	Predicted values of Path loss (dB)	Difference Δ
-102.9	12	119.4	96.2	23.2
-102.4	7	99.1	99.1	19.8
-98.7	9	97.5	97.5	17.7

In the second scenario, the measurement of the path loss in some selected points is depicted in figure 5.2. The impact of the obstacles which are located in the path of the propagation is very clear.

Table 3. Measured and predicted path loss (scenario2)

Rx(dBm)	No of walls	Measured values of path loss (dB)	Predicted values of Path loss (dB)	Difference Δ
-97.5	4	96	74.2	21.8
-84.7	5	101.2	85.4	15.8
-78.6	5	95.1	81.3	13.8

The difference between the predicted and measured path loss in some cases are high and the model is unable to show a

good accuracy due to other factors such as, obstacles of different kinds of materials, which had not been taken into consideration.

6.2. Results and Analysis of Lafortune Model Improvement

The propagation is obstructed by walls and obstacles. The attenuation is increasing as the number of obstacles increase. Tables II &III depict some selected values of the path loss vs. the number of obstacles in case of measured and predicted values of the path loss.

To improve the model’s performance, results from multiple buildings should be incorporated. The idea behind that is to conduct signal strength measurements in different floors; in the first stage; of OLIN building, and analyzing the data to find out if there is a possible improvement of the model proposed by Laforune by adding correction factor, for example. After taking the concrete walls into consideration, the prediction of the path loss inside the building is getting more accurate than in scenario 1&2 (No concrete walls).

Figure 8 & 10 depict the verification of Lafortune model when the concrete walls are considered in computation of the path loss through the walls.

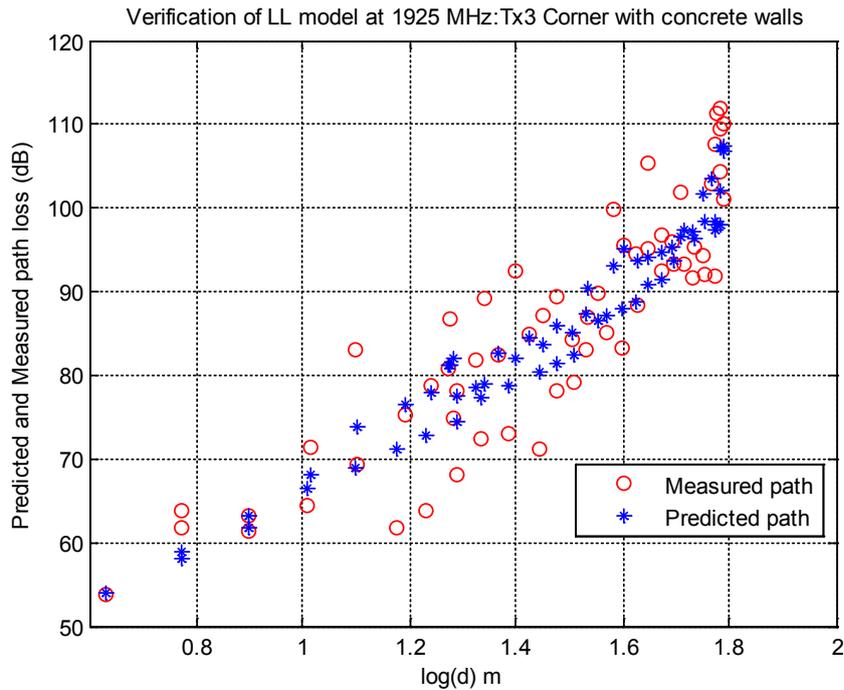


Figure 8. Verification of Lafortune model (scenario 1 with concrete walls)

TX3 Conner with Concrete walls: Mean = -1.89 dB, Std = 5.94 dB , No of measurements = 61

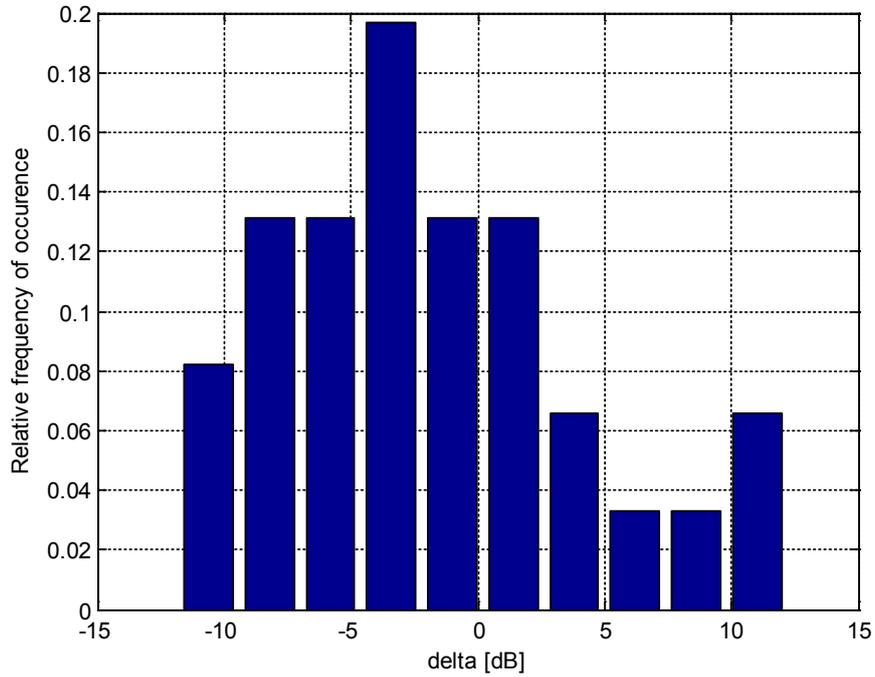


Figure 9. Error histogram (Scenario 1 with Concrete walls)

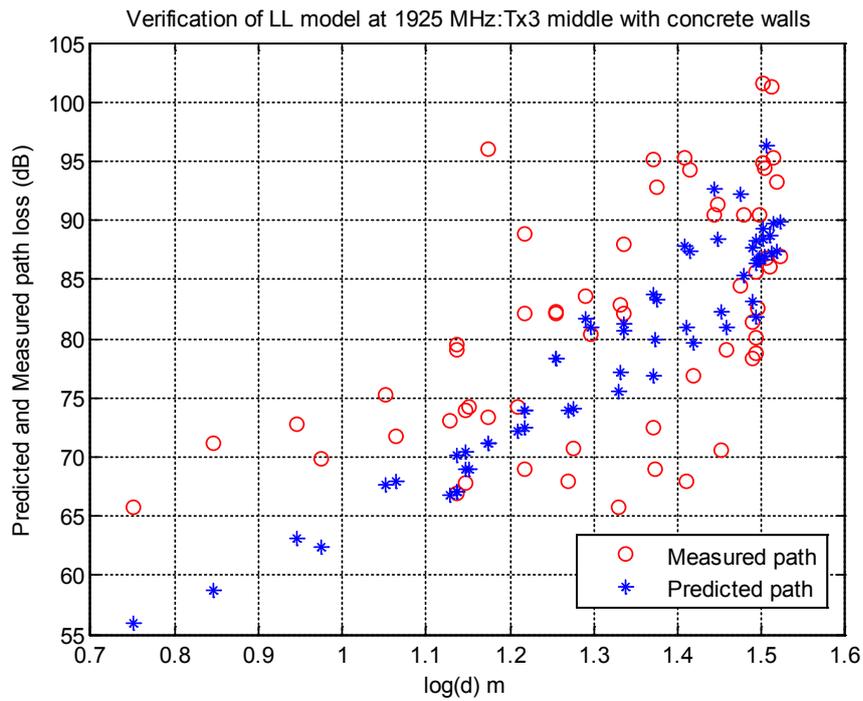


Figure 10. Verification of lafortune model (scenario 2 with concrete walls)

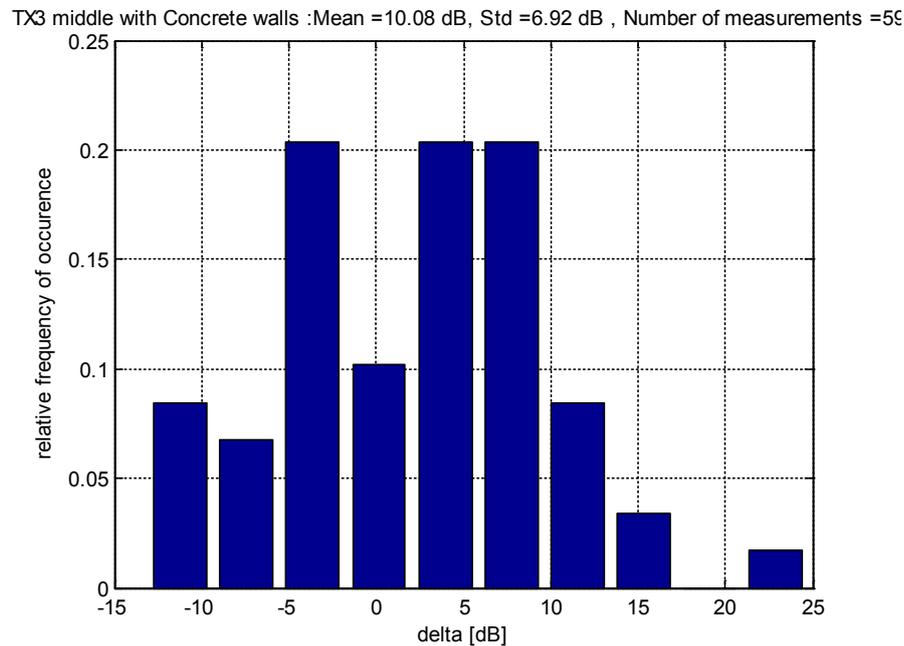


Figure 11. Error histogram (scenario2 no concrete walls)

After taking the concrete walls into consideration, the modified model shows a good accuracy and the difference between the measured and predicted values of the path loss is getting less compared to the case when the concrete walls are not taken into account.

In scenario 1, the error is getting less with average of 0.38 dB and standard deviation of 5.95 dB, while in scenario 2, the average error is 2.36 dB with standard deviation of 7.53dB.

7. Conclusions

In this paper we have presented and analyzed the results of a path loss measurement campaign conducted in an indoor environment. The campaign was set up specifically to validate and develop Lafortune-Lacrous indoor propagation model inside three story building at Florida Tech.

The measurements are collected in 1900MHz band which is one of the principal bands for the deployment of the LTE and LTE-Advanced. The study is conducted using one transmitting and receiving antenna inside OLIN engineering building. The received signal strength is measured inside the building in points around the hallways with 8 foot in between. Additionally, measurements were conducted inside the building at receiving antenna height of $h=0.72$ m.

The work presented in this paper achieved two major contributions. Firstly, examining the validity of Lafortune-Lacrous model for indoor propagation. Secondly, a modifying the model to suit other indoor environments different that adopted in model conducted by Lafortune by adding suitable correction factors.

Regarding the first contribution, it was found that the indoor path loss may be modeled with good accuracy with a

slightly modified log-distance propagation model. The empirical path loss models for two different measurements scenarios are presented in this work. The parameters and factors to be added to the original model were determined from experimental studies and through the appropriate data evaluation process.

The validity of Lafortune indoor propagation model is examined by comparing their path loss predictions to the measurements. The results of the analysis reveal that the applicability of the model in different indoor environments should be carefully investigated. Therefore, appropriate correction factors were added to their original forms to make Lafortune model performs adequately.

With the proposed correction factors, the modified model showed good agreement with measurements. Furthermore, it is concluded that with proper correction factors, a good prediction with reasonable accuracy can be achieved.

As a final comment, the proposed modified Lafortune model might be used to predict the path loss at any environment that is similar to of OLIN engineering building in 1900 MHz band with careful consideration of the location of the transmitter.

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