Experimental Validation of Lafortune-Lecours Propagation Model at 1900 MHz

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Abstract— **This paper documents results of a measurement campaign. The goal of the campaign is to verify if the Lafortune-Lecours*in-building* propagation model may be extended to 1900MHz band. The results of the campaign establish that the model may be used in the 1900MHz band. For the data collected in this campaign the predictions of the model are unbiased and with standard deviation of the prediction error on the order of 5.7dB.**

Index Terms— **In-building propagation, cellular systems, propagation modeling, and path loss estimation.**

I. Introduction

With an ever increasing demand for cellular voice and data services, many of the cellular providers are finding deployment of the in-building infrastructure inevitable. The in-building deployments allow for further re-use of the allocated spectrum and hence, they provide one of the most effective ways for increasing the overall system capacity. However, such deployments face some formidable challenges. The performance of the in-building systems depends heavily on the characteristics of the indoor radio channel. Excessive path loss within the building can cause lack of coverage. On the other hand, infrastructure heavy deployments may result in excessive self-induced interference. Thus, just like their outdoor counterparts, the in-building systems require careful planning which should maximize the coverage and minimize interference. An essential part of the planning process is modeling of the radio channel and its path loss.

The indoor mobile radio channel is not easily modeled. The channel varies significantly from one building to the other. Furthermore, the channel depends heavily on factors which include building structure, layout of rooms, and the type of construction materials used.

There have been several studies of wireless propagation inside building. Some of them with statistical approach channel modeling are given in [2]-[5]. Out of these models, the one proposed by Lafortune and Lecours [1] is very appealing. It is relatively simple and straightforward to implement and according to the authors, it provides quite accurate predictions of the path loss in the 900 MHz band. The goal of the measurement campaign presented in this work is to investigate the validity of this model for the 1900 MHz frequency band. This band is the Personal Communication Band (PCS) band used in many areas of the world for deployment of cellular communication systems. Also, the band is close in frequency domain to some other commonly used bands (2.1GHz, 1800MHz, 1700MHz, etc.). As a result, one should reasonably expect that the conclusions drawn for 1900MHz (possibly with some minor modifications) still hold for the other cellular bands that are close in the frequency domain.

The outline of the paper is as follows. Section II presents the basics of the Lafortune-Lecours model. The environment used for testing is described in the Section III. The measurements are presented in Section IV and some conclusions based on the measured data are drawn in Section V.

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II. Lafortune-Lecours model

Lafortune and Lecours proposed a path loss prediction model for the in-building environment. The model is derived as a generalization of the path loss measurements from two office buildings. The measurements are collected at the carrier frequency of 917 MHz.

The prediction method proposed by Lafortune and Lecours requires knowledge of the building configuration and type of obstruction such as, walls, for instance. The required information is of a detail typically found in building construction plans. For most modern buildings, these plans are readily available. As a result, the model is highly practical and easy to utilize for the RF planning purposes.

There are three phenomena of interest while studying the propagation behavior inside buildings. Those are mentioned as “transmission “, “reflection”, and diffraction.

Transmission refers to propagation losses due to obstacles. Reflection refers to the signal gain which can be experienced when transmission and reception are taking place in the same measurement point such as, in a room. The last phenomenon is the diffraction which refers to propagation around corners or adjacent corridors.

1. Summary of the Lafortune-Lecours model

The basic equation for the prediction of the received signal level is given by:

$$P_R = P_T + G_R + G_T + L_{FS} + L_{OB} + G_{RM} \qquad (1)$$

Where P_T represents the transmitter conductive power expressed in dBm, G_T and G_R are transmit and receive antennas gains expressed in dB, L_{FS} is the free space loss, and L_{OB} and G_{RM} are two correction factors introduced by the model.

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The free space losses are calculated in accordance with

$$L_{FS} = 20\log\left(\frac{\lambda}{4\pi d}\right) \qquad (2)$$

Where λ the wavelength, and d is the straight line distance between the transmitter and the receiver.

For calculation of the correction factors, the model provides a set of cases and a set of corresponding empirically derived equations. The summary of cases and associated equations is provided in Table I. The table of cases and associated equations summarizes only the cases that pertain to strictly in-building and single floor propagation.

From Table I, one readily observes that the model identifies many different propagation cases. The definition of the cases is somewhat qualitative and as a result, one may expect to see differences in different application of the model. Also, one may note, that all the equations for correction factors are derived using path loss measurements obtained at 900MHz. This raises a question of their validity when used in different frequency bands.

Table I. Cases for calculation of correction factors in Lafortune –Lecours model at 900MHz. Note: all distances are in meters.

Case	Description	L_{OB}, G_{RM} in dB
C.1	n walls between TX and RX	$L_{OB} = 3.7 - 1.5n - 10.7\log(d) + \begin{cases} 0, & \text{if } d' < 4\text{m} \\ -7.8 + 15.3\log(d'), & \text{if } d' \geq 4\text{m} \end{cases}$ Where d' is the distance to the closest wall. Note: Corner uses n = 1, thin wall uses n = ½ and a thick wall may use n = 2. $G_{RM} = 0$
C.2	Door between antennas	y: distance behind the door, θ: angle between TX-RX line and door wall • Door open ($\theta > 30^\circ$), no other wall If $y \leq 2$, then $L_{OB} = 0$, $G_{RM} = 2$ If $2 < y < 10$, then $L_{OB} = 0$, $G_{RM} = 0$ If $y > 10$, then $L_{OB} = -1$, $G_{RM} = 0$ • Door closed If $y \leq 2$, then $L_{OB} = -2$, $G_{RM} = 0$ If $y > 2$ use case C.1 with n = 1 • Doors and walls (x_1 door) Use case C.1 with $n = x_1 + x_2$
C.3	Windows between antenna	1 window, $\theta > 45^\circ$, $L_{OB} = 0$, $G_{RM} = 0$ 1 window, $\theta < 45^\circ$, use C.1 with n = 1 1 window, x walls, use C.1 with n = x 2 windows, use C.1 with n = 1 2 windows, x walls, use C.1 with n = x 3 windows, x walls, use C.1 with n=x+1
C.4	Furniture between antennas	Non-metallic furniture L_{OB} = Case C.1 − 1, $G_{RM} = 0$ High, metallic furniture with wall L_{OB} = Case C.1 − 2, $G_{RM} = 0$ High, metallic furniture without wall $L_{OB} = -4$, $G_{RM} = 0$
D.1	Emission in main corridor	Main corridor, no transversal doors: $L_{OB} = 0$, $G_{RM} = 0.2 + 1.8\log(d)$
D.2	End of corridor	Last 8 meters: $L_{OB} = 0$, $G_{RM} = 1.6 + 3.9\log(d)$
E	Lateral corridor, opening in main corridor	E.1: No door at the junction: $L_{OB} = -5.6 - 12\log(h+1)$, $G_{RM} = 0$ Where h is 'geometric diffraction parameter' E.2: Door at the junction Door open: same as E.1 Door closed: $L_{OB} = -7.6 - 11.5\log(h+1)$, $G_{RM} = 0$
F	Room adjacent to corridor (d> 30m)	$L_{OB} = -7.6 - 11.5\log(h+1)$, $G_{RM} = 0$
G	Emission in the same room	$L_{OB} = 0$, $G_{RM} = 0.2 + 1.8\log(d)$

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III. Model Verification at 1900 MHz

The 1900MHz path loss measurements used for the model verification are collected in a three-story building at the campus of Florida Tech. A Continuous Wave (CW) transmitter is used. The transmitter operating frequency is 1925 MHz with a transmit power of 6dBm. For the measurements reported in this paper, both the transmitter and the receiver are located on the same floor of the building.

The third floor plan of the building is presented 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 made out of concrete white brick. The height of ceiling is 9' 2" covered with "acoustic" ceiling pressed fiber tiles. The size of surveyed area is 20,770 square feet.

During measurements transmitter and transmitting antenna are kept stationary while the receiver is moved between measurement points. The measurements are taken when the receiver is standing still. The measurement points are 8 feet apart in the hallways throughout the building.

The measured signal strength is averaged at each point to eliminate the fast fading from the motion of the environment that is surrounding both the transmitter and the receiver. The averaging time is three minutes. Therefore, the measurements represent the average path loss.

IV. Experiment Scenarios

The investigation considers two experimental scenarios. The scenarios are describes as follows.

A. Scenario 1

The transmitter is mounted inside a room located in the corner of the building as depicted in Fig.2. In this scenario, all measurement points have no line of sight. Before being measured the signal has to pass through at least one obstruction.

B. Scenario 2

The transmitter is placed in the middle of the building. In this scenario, many measurements have clear line of the sight to the transmitter.

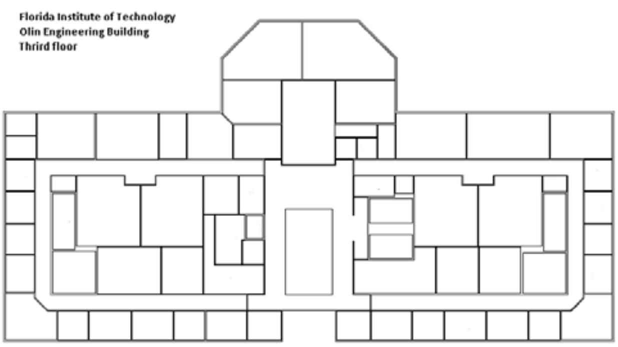

Fig. 1: OLIN engineering building

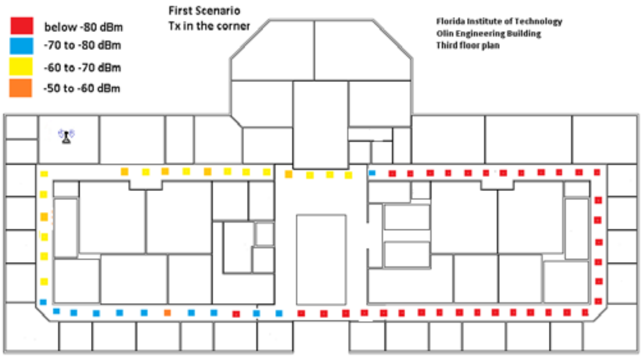

Fig.2: First measurement scenario

Also, for the measurement points that do not have LOS, the signal is propagating through specular reflections from the floor, ceiling and the building walls. The outline of the measurements in the second scenario is presented in Fig. 3.

As seen, the two scenarios cover two different propagation cases as they are identified in [1] as well.

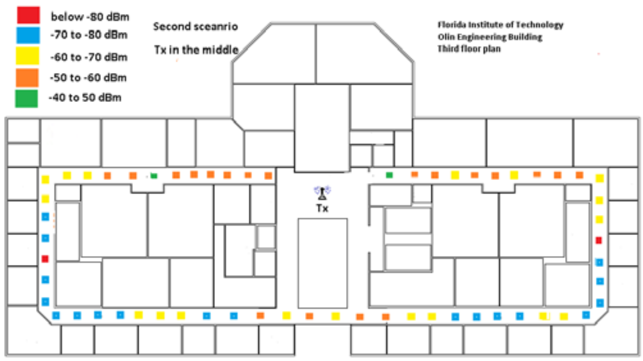

Fig.3: Second measurement scenario

V. Measurements and Results

The signal strength inside the building is measured. The signal strength is decreasing as the distance increases. The transmission path is obstructed by walls and there are line of Sight (LoS) measurements.

As depicted in Fig.2 and Fig.3, the signal strength decreases as a function of the distance between the transmitter and receiver and the number of obstacles located in the path of propagation. In some locations, the signal experiences high loss because of the number and kind of obstacles that are on the path of radiation. The red spots represent where the severe loss of signal that might occur due to presence of different kind of walls other than in the rest of the building (Brick and concrete in this specific case).

The path loss caused by the existence of obstructions is expressed as in section C1 in Table I. Due to refraction from the walls, the signal attenuation is smaller because of the gain caused by the refraction. The gain is expressed as in section G in table I. The signal strength deteriorates as the distance increase. As depicted in Fig.4 and Fig.8, different measurement points that have almost the same distance experience a comparable signal streangth.

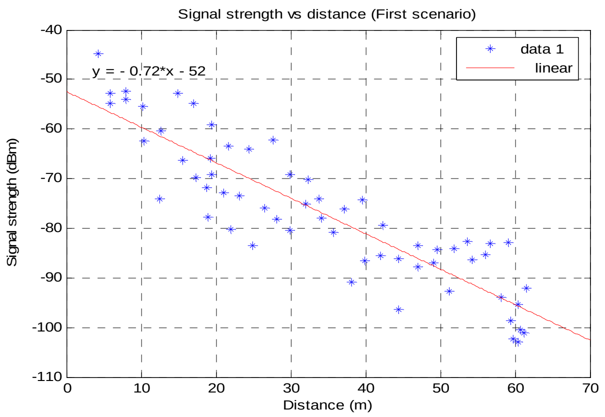

Fig. 4: Signal strength vs. distance (scenario 1)

The path loss is computed according to Lafortune-Lecours model and compared to the measured values of the path loss resulted from the measurements as seen in Fig. 5. To investigate the validity of Lafortune-Lecours model, the results of the measured values of path loss are compared and can be shown in Fig. 6.

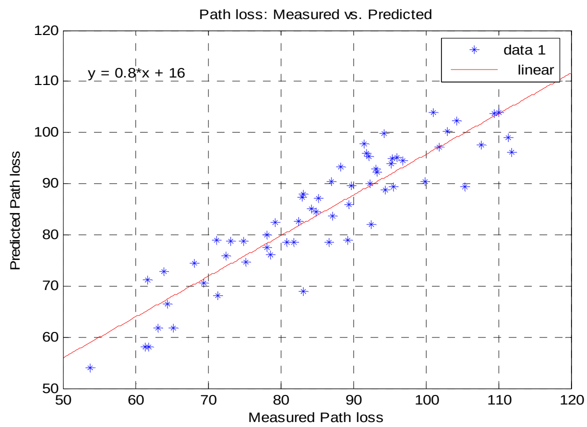

Fig.5: Measured path loss vs. Predicted Path loss (scenario 1)

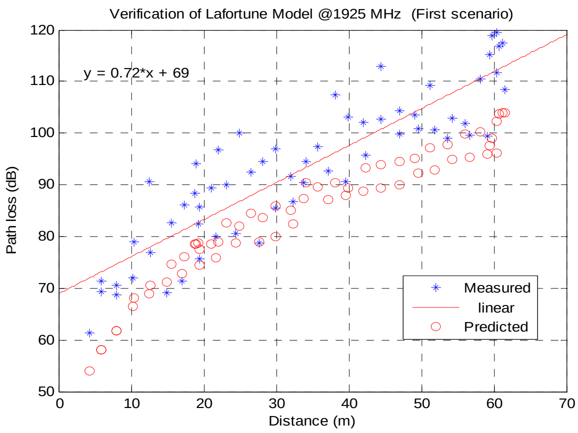

Fig. 6: Verification of Lafortune-Lecours model at 1925 MHz.(Scenario 1)

The difference between the measured and predicted values of the path loss is depicted in two scenarios of measurements (different position of Transmitter antenna). The error resulted from the difference between the predicted and measured path loss is shown in a histogram form (Fig.7 and Fig.11).

The difference between the values of path loss predicted by Lafortune-Locours model and the measured values from the experiment is calculated. The standard deviation is 5.7 dB. There is some measurements show big difference between the predicted and measured path loss where the signal path goes through different type of obstructions.

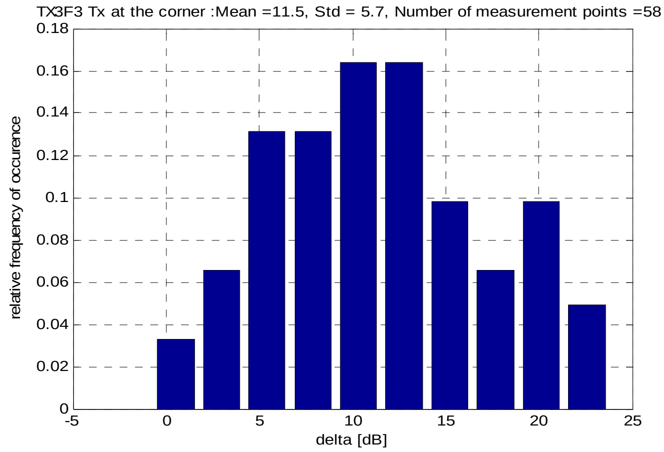

Fig. 7: Error histogram where Transmitter at the building corner (Room 343)

Table II. Predicted and Measured values of Path loss (scenario 1)

Rx (dBm)	No of walls	Path loss Measured(dB)	Path loss Predicted(dB)	Delta
-94.9	7	111.4	95.4	16
-99.8	9	116.3	97.1	19.2

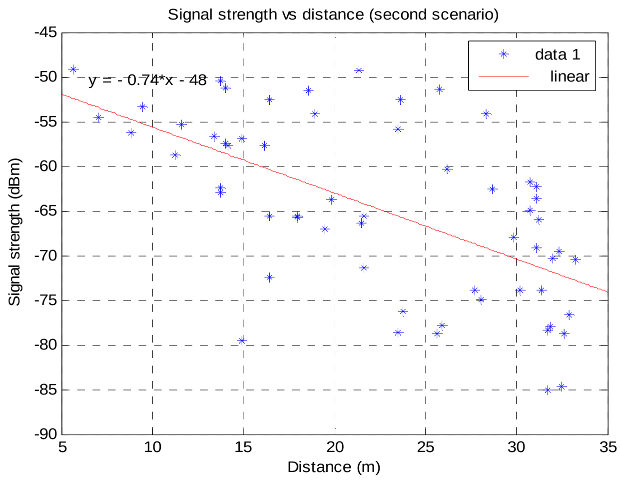

Fig.8: signal strength vs. distance (scenario 2)

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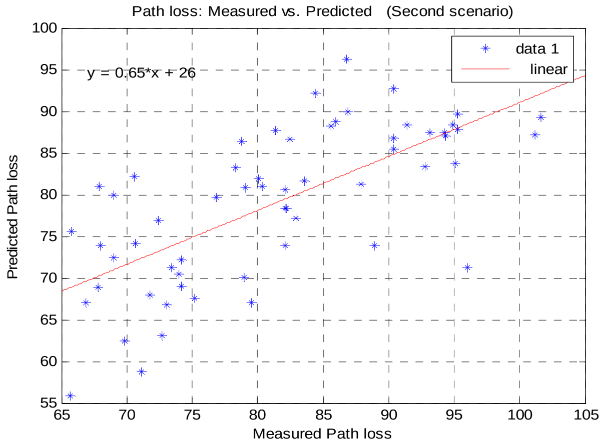

Fig.9: Measured path loss vs predicted path loss (second scenario)

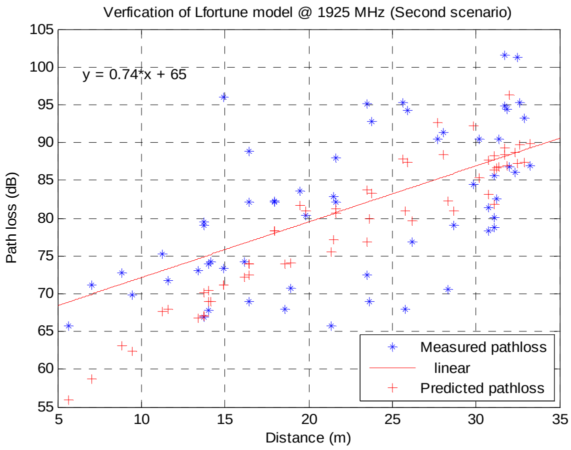

Fig.10: Verification of Lafortune model at 1925 MHZ

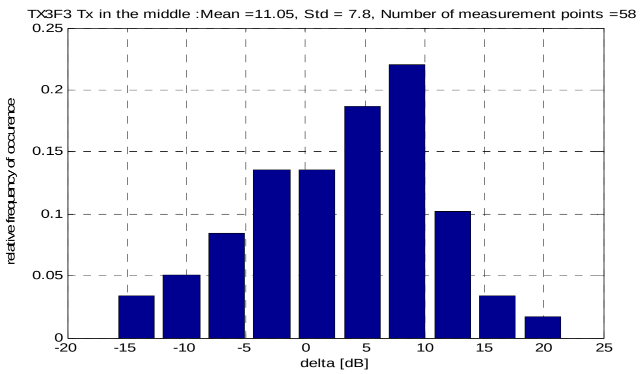

Fig. 11: Error histogram where Transmitter in the middle of the building

Table III. Predicted and Measured values of Path loss (scenario 2)

Rx (dBm)	No of walls	Path loss Measured(dB)	Path loss Predicted(dB)	Delta
-79.5	4	96	74.2	21.8
-99.8	9	116.3	97.1	19.2

In this case, the measured values of path loss are greater than path loss values predicted by Lafortune model.Table II.depicts some path loss values where the radiation path is obstructed by walls made of concrete bricks.

By taking a look at the tables II & III, it can be clearly seen the effect of the brick walls. The difference between the two values of the path loss is quite large.

In the first scenario, the average error resulted from the difference between the predicted and measured is 11.5 dB with 5.7dB standard deviation.

In the second scenario, the average difference between the actual and predicted values of the path loss is 3.03dB while the standard deviation is 7.8 dB. By comparing both scenarios, we find that standard deviation of the difference between the actual and predicted values in the first scenario is less than that of second scenario.

VI. Conclusions

Lafortune-Lecrous model shows a good approximation in the second scenario (where the transmitter is mounted in the middle of the building) when compared to the results got from measurements.

In the second scenario, the error average of the difference between the actual and predicted values of the path loss is 3.03 dB with standard deviation s 7.8, which is greater than that of first scenario because of the transmitter location. Since the transmitter location was in the middle of the building as depicted in Fig. 3, the amount of reflection is higher than that of first scenario. That is why the model shows almost 2 dB difference when the location of the transmitter had been changed.

Some values of Delta as depicted in table I show a large difference and needed to be interpreted again as the Lafortune –Lecrous model is incapable to show an acceptable approximation.

Due to different wall materials, Lafortune model did not take into consideration thick solid wood door and concrete or brick walls. Because of the large error between the predicted and measured values of the path loss in case of brick walls, a further investigation is to be done to minimize the resulting error and to adapt the Laforune-Lecours model to be used to include different obstacles in computation of the path loss.

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