Optimizing the Existing Indoor Propagation Prediction Models

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Abstract. Mobile stations are more frequently used within the home and work-place. Thus, they require better indoor services. Modeling indoor propagation is complicated by the large variability in building layout and construction materials. For initial system planning, it is necessary to estimate the number of base stations to provide coverage to distributed mobile stations within the area and to estimate potential interference in the systems. For these system planning cases, models that generally represent the propagation characteristics are needed. In this study the most applicable propagation indoor models such as COST 231 Multi Wall, Long-distance path loss, Dominant path loss model and comparison of their prediction accuracy were discussed. Optimization is done using statistical approach. The MSE were found 6 dB and 5.34 dB for optimized Dominant Path Model and COST231 Multi-Wall Model respectively which is an acceptable value for the signal prediction. The path loss exponent for Long-distance path loss also determined $\gamma = 2.2$. Thus, the optimized model has achieved better precisions results.

Keywords: Indoor, path loss, prediction model, received signal strength.

1. Introduction

Indoor microcellular systems are becoming very important for providing wireless voice and data communications within the home and work-place [10]. In many countries 80% of users are inside buildings, and providing high-performance indoor coverage, especially on higher data rates, is a challenge. It is much more than a technical challenge; the business case must also be evaluated, as well as future-proofing of the solutions implemented, among other considerations [4].

Indoor systems tend to be complex, with the radio wave encountering many obstacles that give rise to multiple diffractions and reflections. The electrical characteristics of the materials are often only vaguely known and, to make the situation more complicated, people, furniture and even walls can be moved. Nevertheless, buildings and, in particular, high-rise office buildings contain many potential users of telecommunications systems and could provide significant revenue if a high-quality radio communication service could be delivered. Although the distances between transmitter and receiver are usually very small, the existence of multiple obstructions (such as walls and floors) means that the path loss can be quite high and difficult to predict[2,8,13]. It appears that propagation totally within buildings is more dependent on building layout in the 1800 MHz band than it is at 900 MHz [11,12]. Adding all these variables together produces a very complex problem that has to be dealt with efficiently and elegantly. Therefore, giving an accurate answer to each indoor communication system using the same models is complex. Path loss is difficult to calculate for an indoor environment [6].

There are two general types of propagation modeling: site-specific and site general. Site-specific modeling requires detailed information on building layout, furniture, and transceiver locations. Site-general models provide gross statistical predictions of path loss for link design and are useful tools for performing initial design and layout of indoor wireless systems [5]. For this paper empirical or statistical model (such as long-distance path loss) and deterministic model (such as Dominant path loss) were considered.

1.1 Methodology

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From this study a distributed antenna system was used to deploy a wide indoor coverage by means of a single transmitter.

- Tools: Test phone; GPS system; Laptop equipped (Drive test tools); Mapinfo. In addition to this for simulation purposed RF-vu PRO and Matlab software were used.
- The Rx level signal was collected up to 70 meter from the indoor antenna (inside SH-AD Hotel) and subdivided with 10 m interval.
- To determine the optimized path loss exponent value γ in long distance path loss modelthe least squares method was applied using mathlab software. On the other hand to simulate COST 231 Multi Wall and Dominant path loss model RF-vu PRO tools was used. For these models the optimization were done by subtracting the standard deviation from predicted path loss value.
- The optimization (modification)activity provided the final result for this study

2. Indoor Propagation Models

2.1. COST231 Multi-Wall Model

This model of propagation within buildings incorporates a linear component of loss, proportional to the number of walls penetrated, plus a more complex term which depends on the number of floors penetrated, producing a loss which increases more slowly as additional floors after the first are added [1].

$$L_T = L_F + L_C + \sum_{i=1}^{w} L_{wi} n_{wi} + L_f n_f^{((nf+2)/(nf+1)-b)} \tag{1}$$

where L_F is the free space loss for the straight-line (direct) path between the transmitter and receiver, n_{wi} is the number of walls crossed by the direct path of type i, w is the number of wall types, L_{wi} is the penetration loss for a wall of type i, n_f is the number of floors crossed by the path, b and L_C are empirically derived constants and L_F is the loss per floor.

2.2. Indoor Dominant Path Prediction Model

The Ray approximation has been used to predict the propagation characteristics within building. This models use ray tracing models in two or three dimensions for prediction that include both reflection and transmission at walls, ceiling and floor [3]. For the computation of the field strength (as well as power or path loss) several propagation effects are considered. The equation used for the computation of the field strength E in dBμV/m

$$E = 104.77 \frac{dB\mu V}{m} - 10.p.\log\left(\frac{d}{m}\right) - \sum_{i=0}^{n} f(\varphi, i) - \sum_{j=0}^{m} (t_j) + \frac{1}{c}\sum_{k=0}^{c} w_k + g_t + p_t \tag{2}$$

Equation for the field strength E in dBμV/m

The definition of the parameters:

d Distance (along the path) between transmitter and current receiver pixel

p Path loss exponent, depending on the current propagation situation

$f(\varphi, i)$ Function for individual attenuation for each interaction i of all n interactions

t_j Transmission (penetration) loss for each penetration j through a wall

w_k Gain caused by wave guiding for each pixel along one propagation path

g_t Directional gain of transmitting antenna in direction of propagation path

p_t Power of transmitter in dBm

2.3. The Log-Distance Path Loss Model

The log-distance path loss model is site-general model and it is given by [6,5]

$$L(d) = L(do) + 10\gamma \log\left(\frac{d}{do}\right) + Xs \quad dB \tag{3}$$

$$L(do) = -120\log(\lambda) + 20\log(4\pi) + 20\log(1) \tag{4}$$

Where: $L(do)$ is the path loss at the reference distance, usually taken at (theoretical) free-space loss at 1m

γ is the path loss distance exponent

Xs is a Gaussian random variable with zero mean and standard deviation of σ dB.

This empirical model takes into account the effect of shadowing by introducing Xs , which describes the statistical character of slow fading within the indoor link and, as a random variable, satisfy the long normal distribution with a standard deviation of σ in decibels [5,16,13].

3. Data-Fitting Methods in Path-Loss Modeling

An empirical model like the Long-distance path loss models is based on measurements. The most straightforward approach to data fitting is the least squares approach. Consider the linear case

$$yi = ax_i + b + e_i \tag{5}$$

Where: e_i represents the measurement error.

In order to find the best parameters $a \ and \ b$, a natural cost function is the overall cumulative error

$$J(a,b) = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N}(y_i - ax_i - b)^2 \tag{6}$$

Which is to be minimized with respect to a and b. It is straightforward to solve the analytical expressions for the optimal a and b[17]. The MMSE error equation for the dB power measurement is

$$F(\gamma) = \sum_{i=1}^{n}[M_{measured \ (di)} - M_{model}(di)]^2 \tag{7}$$

Where M $_{measured \ (di)}$ is the path loss measurement at distance di, and M $_{models(di)}$ the selected path loss based. The standard deviation:

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}[M_{measured \ (di)} - M_{model}(di)]^2 \tag{8}$$

The Error function can be defined [15]: $Q(z) = \int_{z}^{\infty} \frac{1}{\sqrt{2\pi}} exp\left(-\frac{u^2}{2}\right) du$ (9)

4. Simulation and Result Analysis

Simulation Parameter and assumption is shown Table 1

Table 1: Network Parameters

Frequency Band	1800 MHz
Antenna	17dBi
Sigma (σ)	9.6
Floor height(m)	4
Area (Sq.Km)	600
Coverage target	95%
Omini directional antenna gain	2 dB
Directional antenna gain	2 dB
Yagi Antenna gain	10dB

Table 2: Measures Value

T-R distance (m)	Path Loss Value (dB)
10	38
20	41
30	48
40	51
50	61
60	72
70	80

The data were carried out through drive test and field trace mobile inside the SH-AD Hotel and variation of the received signal strength with distance shown in Table 2.Figure (1) showsthe coverage predictions using deterministic (path-searching) or Dominant Path Prediction Model. The Rx signal varied from -50dB to -83 dB with in the distance range 10m to 70m.This prediction run using RF-vu PRO tools.
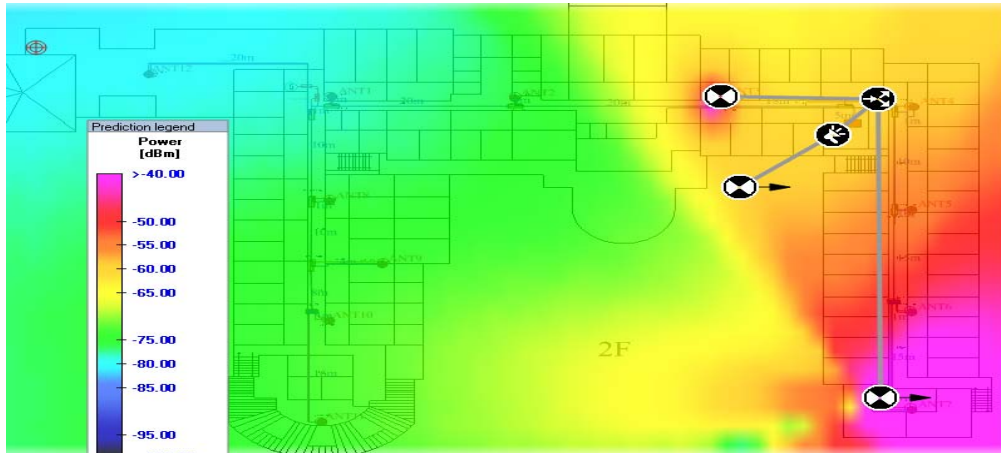
Fig. 1: Signal prediction based on dominant path Model

Considering coverage 95 %, and using "(9)", or Error Function table, Z=1.645 the value for Xs become 11.3. Setting the dervative mean sequre error zero using "(7)", and solveing for γ yields a path loss exponent of 2.2. Substituting this value into "(3)", gives

$$L_T = 26.8 + 10 * 2.2\log{(d)} \qquad (10)$$

Based on measured data the mathematical representations for the long distance path loss model were modified (see "(10)",) that would best describe the behavior observed in the measured data. This optimized model present the actually start with a mathematical description of the environment and then provide the prediction of the path loss by considering the specific value $\gamma = 2.2$ and gives standard deviation log-normal distribution 10dB (see Fig. 3)

In order to take into account the path loss comparison, the Rx value convert to path loss value using link budget analysis for the case Dominant Path model and COST 231 Multi-Wall . Equation 10 used to predict path loss for Long-Distance Path loss Model. The result is plotted in Fig. 2.
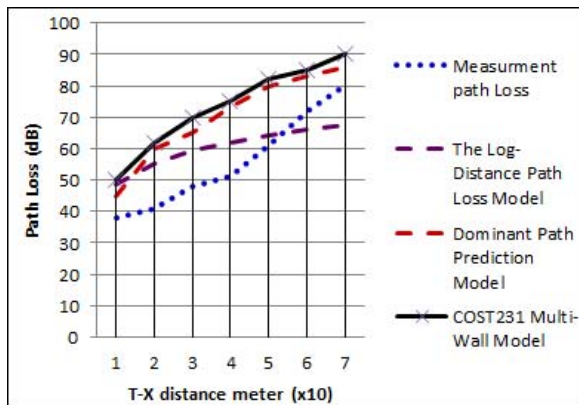

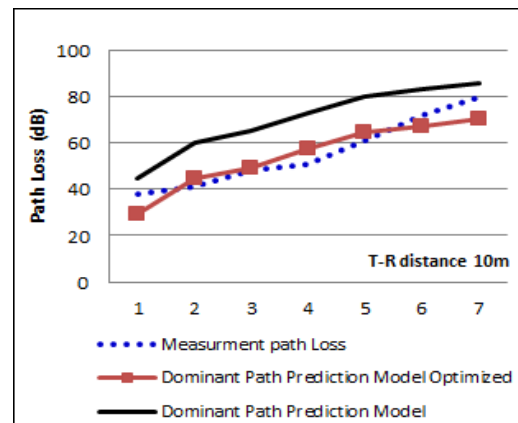Fig.2:Path Loss Comparison for different model

Fig. 3:Path Loss Comparison for Dominant Path model

The measured value indicates that the standard deviation is more in COST231 Multi-Wall Model (Sigma=18.34) than Dominant Path Prediction Model (Sigma=15.6).After the substitute of path loss exponent (γ=2.2) the error for the Long Path loss Model is 10 dB, and further improvement also achieve by optimizing "(10)". Both existing models (COST231 Multi-Wall Model and Dominant Path Prediction Model) were overestimated the loss comparison with measurements since acceptable mean square error range is up to 6 dB.The optimizing process was done by decreasing the MSE (mean square error) from the predicted path loss and the results were shown in Fig.3, Fig.4 and Fig.5.

Fig. 3 illustrates the optimized models exhibit roughly the same path loss with respect to measured results. It has been observed that the optimized Dominant Path prediction model improve the signal

prediction, i.e., the standard deviation decreased from 15.6 dB to 6 dB.This implies that the error decreased more than 50% (i.e. signal prediction accuracy increased)
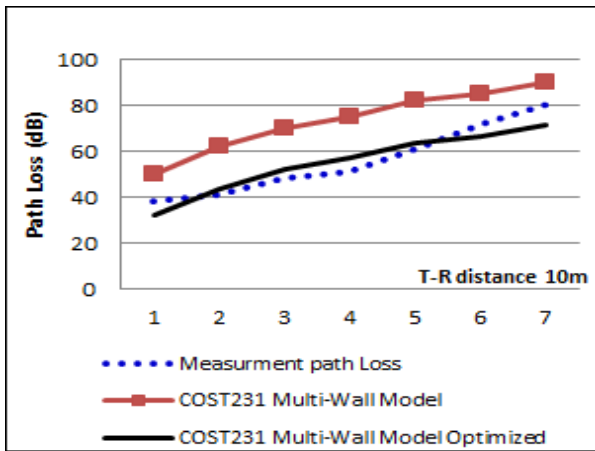

Fig.4:Path Loss Comparison for COST 231 Multi-Wall model
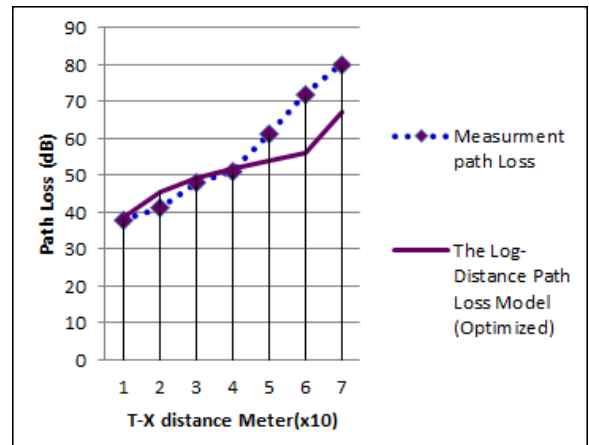

Fig.5:Path Loss Comparison for the long-distance mode

From the comparison (see Fig. 4) we have seen that the modified COST 231 path loss curves have somewhat similar slopes with the actual measured path slop especially till the separation distance between transmitter and receiver equals 600 meters. This illustrates the modified path loss models predict better than the existing COST 231 simulated path loss value, typically for this scenario. The standard deviation for the optimized path loss become 5.3 which was lower than the Non-Optimized COST 231 path loss model (Sigma=18).

Finally the MSE was subtracted from the path loss equation "(10)" then it was plotted in Fig.5. Using modified equation "(11)" the MSEdecreased to 8 dB

$$L_T = 16.8 + 10 * 2.2 \log(d) \tag{11}$$

5. Conclusion

Indoor model of the environment is a useful design tool in constructing a layout that leads to efficient wireless communication strategies. To achieve this aim, optimizing existing model of an indoor environment must be applied to various layout plans. By examining the details of propagated signal level from the transmitter to the receiver for a number of experimental locations, the optimization model were developed that highlights the important characteristics of a given indoor environment to precisely predict the indoor path loss signal.

From this study optimized modelresults have revealed that the MSE could be decreased to 9.6 dB and 13.04 dB in the optimized Dominant Path Model and COST231 Multi-Wall Model respectively. Optimized path loss exponent value was determined for long-distance path loss mode; $\gamma = 2.2$ and the corresponding standard deviation σ=10dB. The result clearly shows that the optimized models were improved the signal prediction accuracy and would be reliable to be applied in the indoor buildings.

6. Acknowledgments

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