Comparison between Propagation Models for Wireless Applications

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1. Introduction:

1.1 Brief introduction to propagation model

Propagation models are empirical mathematical formulations to characterize how radio waves behave as a function of frequency, surrounding environment and distance. Several propagation models exist for different link scenarios and these are helpful to service providers for designing and deploying their networks in the best possible way [1].

1.2 Current industry standard

Currently separate propagation models exist for indoor and outdoor environments. Majority of the wireless systems are made up of outdoor macro cellular networks. But in recent times the use of wireless devices in indoor environments has greatly increased which has resulted in major changes in design considerations for outdoor as well as indoor wireless networks [3]. The indoor models do not take into account the effects of an already deployed outdoor system while making calculations and vice-versa. Current methodologies include the 3D ray tracing model and the interpolation of data collected from the walk test.

1.3 Hybrid Propagation model

EDX Wireless, a pioneer in wireless network design and planning tool technology, has proposed a new propagation model which addresses the aforementioned problem. It has proposed a "hybrid propagation model" which is based on the combination of an indoor and outdoor propagation model [5]. It combines the features of Anderson 2-D model for outdoor and the EDX Simplified Indoor Model (ESIM) for indoor environment.

2. Research Topic:

2.1 Proposal

We would be analyzing the current methodologies and the above mentioned hybrid model for outdoor to indoor propagation scenario. In recent times the importance of professional grade in-building networks such as Distributed Antenna Systems (DAS) is increasing in the wireless world [2]. We will test and analyze the hybrid model against current standard 3D ray tracing model. This analysis will help us draw a conclusion as to which model is better in terms of accuracy and computational time in predicting the path loss when compared against the measured data.

2.2 Importance

The macro cellular networks greatly affect the design of the indoor wireless networks in terms of the power level settings of the indoor antennas, antenna placements and other similar issues [3]. So it is necessary to include the impact of the outdoor propagation parameters when designing the indoor networks. This will assist the network operators to design indoor wireless networks and select the correct design parameters. We chose to use the frequency of 765.5 MHz which falls under the NIST public safety band. As per [3], the smart grid technology also makes use of indoor wireless networks and this project could be of help for smart grid as well.

2.3 Relevant prior research work

There are many hybrid models proposed in to address the question as mentioned in [2, 4]. But none of those previous works have made use of the models like Anderson 2D model and the ESIM, also the frequency range is different.

3. Definitions

Path loss - The path loss is the difference (in dB) between the transmitted power and the received power [9].

Propagation model: It is an empirical mathematical formulation to characterize the behavior of the radio waves as a function of frequency, surrounding environment and distance [1].

Service area network: Geographical area in which wireless service providers offer their service or coverage.

3D Ray tracing: Ray tracing is a graphical method to calculate the path taken by the radio waves through a given environment. 3D ray tracing involves taking into account the rays arriving at the receiver after reflecting from all the possible reflecting surfaces. These surfaces may also include horizontal roads and vertical building walls [1].

Anderson 2D model – The Telecommunications Industry Association states the definition as- “It is a comprehensive point-to-point radio propagation model for predicting field strength and path loss in the frequency range of 30 MHz to 60 GHz.” It also states that this model takes into account the most important parameters of propagation prediction but still remains simple so that implementation of this model does not require higher computational time. [10]

EDX Simplified indoor model– This indoor model introduced by EDX Wireless is used for planning of in building networks. Signal Pro, the software developed by EDX Wireless allows us to import the building floor plans using AutoCAD files and helps in designing RF propagation for in-building path loss prediction.

Walk test: It is a kind of site survey which involves taking measurements at several data points by walking around in the designated area for the scenario under test.

Interpolation: It makes use of the data points collected in the walk test, which is a limited data, to predict the value of the mathematical function [7].

4. Methodology

4.1 Scope

The research proposed in this paper is limited to measurement and analysis in the CU-Boulder campus. The transmitting system was installed on Folsom Field’s (Football Stadium on CU-Boulder’s campus) rooftop. The signal measurements were taken with the aid of ZK Celltest equipment, ZK-SAM, on all the floors of two eleven-story towers – JILA and Duane Physics on CU Boulder campus. Following the data collection process we will import the measurements into the EDX SignalPro software where we analyzed the collected data and predicted the indoor coverage in the two buildings. Data analysis consisted of importing the data to SignalPro to compare the efficiency and accuracy of 3D ray-tracing model and hybrid propagation model against the measured data. The intended audience for this project will be majorly the wireless service providers who are deploying indoor networks [2], as it will be useful while planning their network.

4.2 Assumptions

The first assumption for this research is that this comparison of propagation models is valid for suburban areas like Boulder. Theoretically, advantage of the 3D ray-tracing model is that it gives a highly accurate prediction but takes more than six hours to predict the coverage. On the contrary, hybrid model can give close-to-accurate prediction in small amount of time as compared to 3D ray-tracing model. So on the basis of time constraints, our second assumption is that the hybrid model is superior to the 3D ray tracing model.

4.3 Procedure

This section will summarize the procedure of our research project. The first step is to decide the frequency of operation. Our goal is to study the characteristics and behavior of propagation models in the LTE frequency band, which is a subject of discussion within the wireless industry. Hence, it is important to ascertain any unused frequency in the upper 700 MHz band [8]. This was identified using a spectrum analyzer and an omnidirectional receiving antenna. After this initial step of testing, we decided to set the transmitting frequency at 765.5 MHz.

The next step was to import the blueprints of the floor plans (in the form of CAD drawings), of the two buildings into the EDX SignalPro software (a RF planning and design software) [6]. The CAD drawings contain details of each floor such as stairs, emergency exits, elevators which are not important in this research project. We removed all these excessive fine points using BuildingEditor, additional software by EDX Wireless, to create an outline of the floor containing only the pertaining information such as hallways, doors, windows and support columns. Using SignalPro, we can also change the wall attributes such as type of wall (reinforced concrete), attenuation at different frequencies (18 dB in our case), thickness etc. While importing the floor plans in Signal Pro, we have to explicitly mention the height of each floor i.e. floor 1 - 0–8 m, floor 2 - 8–11 m, floor 3 - 11–14 m, and so on, in order to get the most accurate prediction from SignalPro.

By default, the imported floor plans were randomly shifted from their actual physical location making it necessary to geo-reference the floor plans to their actual physical location. This was done by manipulating the latitude–longitude fields in SignalPro to set the floor plans to their correct geographical location. After manipulating the floor and building characteristics, we converted these files into JPEG and imported the same into the ZK-SAM.

The third step was to setup our transmitter system on Folsom Field skybox roof. There were many aspects to be considered while setting up our transmitter. We used a directional antenna (gain 3dBi) to transmit the signal at 765.5 MHz with 25 dBm of signal power. Also it was vital to setup the transmitting antenna to transmit at an appropriate angle (248 degrees SW) in order to achieve accurate 'line of sight' to the buildings.

Next, we performed a walk-test in the buildings to take measurements of the received signal on all the floors. We measured the received signal power (RSSI), using the ZK Cell Test Equipment [6], with approximately 600 points per floor so as to get a precise prediction when the values were imported in SignalPro during data analysis. The ZK-SAM has a feature to record the walk-test path while taking the measurements and can also store log of values such as received power in dBm, latitude-longitude of specific points and a list of other values. The above mentioned data from the log was extracted and used for creating Boundary files (.bna) containing the latitude-longitude information of data points recorded which was used in SignalPro simulation. The boundary files imported in SignalPro defined the specific path taken for the walk-test to simulate the route study.

SignalPro software has the ability to fetch Bing maps from the Internet. We used it to geo-reference the transmitter antenna to its correct co-ordinates (i.e. Folsom field rooftop). The properties of the transmitter antenna in the simulation were the same as the real antenna (i.e. transmitting power, operating frequency, azimuth orientation and height above the ground). After the execution of route studies, the SignalPro gave a superimposed illustration (as shown in Figure 1) of the power predicted by propagation model against the measured power. The SignalPro Software shows the recorded path we took during our walk-test. The small dots in the figure indicate the actual measured power, while the bold lines indicate the predicted power levels by SignalPro. The different colors show different power levels at different locations taking into consideration the signal attenuation parameters.

Figure 1. Illustration of a Route Study in SignalPro

5. Measurement Data

As mentioned above, the measured power (in dBm) with the corresponding geo-referenced points was imported in SignalPro to begin the Hybrid and 3D – Ray Tracing Models' analysis. SignalPro provided superimposed graphical data of the route study performed on each floor, along with numerical values for the predicted power. Approximately 600 to 800 data points were extracted from the performed tests. A part of the consolidated data generated by SignalPro (in an excel file format) is shown in Table 1. These predicted values obtained from the route study were compared with the actual measurements and the error (or difference between measured value and predicted value) is calculated for each data point. The error values are then converted to mean error (by calculating the average for cumulative error on all points on that particular floor). Similar calculations are done after performing 3D-ray tracing and obtaining predicted values from the test. The mean error for the two models are plotted into a graph and compared to infer about the preciseness of the models, compared to the actual measurements.

Table 1: The data log generated by SignalPro

Latitude	Longitude	Measured Values*	Hybrid Model	3D-Ray Tracing Model
-105.2684856	40.00743345	-101	-111	-83.2
-105.2684854	40.00743197	-98	-112	-89.1
-105.2684853	40.0074305	-96	-112	-91.9
-105.2684852	40.00742903	-94	-112	-96.5
-105.2684851	40.00742756	-97	-112	-94.5
-105.2684849	40.00742608	-97	-114.2	-83.2
-105.2684848	40.00742461	-95	-120	-83.4
-105.2684847	40.00742314	-104	-114.6	-83.3
-105.2684845	40.00742167	-101	-116.4	-83

*Note: The column containing the measured values was included by us for reader's clarity in understanding the difference between the measured and the predicted power levels. Signal Pro generates only the predicted power levels (i.e. Hybrid and 3D-Ray Tracing Models).

6. Data Analysis

6.1 Graphs and statistics

As mentioned in the earlier section, we calculated the mean error of Hybrid Propagation Model and 3D – Ray Tracing Model. This was done so as to draw the comparison between the two models to deduce the displacement of predicted power of the two models from the measured power. The following tables illustrate the mean error and standard deviation for a set of three floors each from the two buildings.

Table 2: Mean Error of the Propagation Models

	Floor	Error in Hybrid Model (Measured Value - Hybrid Value)	Error in 3D Model (Measured value - 3D ray-tracing value)
Duane	**2**	-7.006678082	-9.320034247
	5	-7.252279635	-8.85212766
	10	1.340857298	-3.772978839
JILA	**2**	4.291608877	-12.15263523
	5	14.34886562	-7.931413613
	10	-13.21490148	-7.936699507

Table 3: Standard Deviation of the Propagation Models

	Floor	Standard Deviation of Error for Hybrid Model	Standard Deviation of Error for 3D Ray-Tracing Model
Duane	2	15.71711023	9.973582223
	5	11.89463135	8.086179843
	10	17.30173956	12.09111209
JILA	2	19.56623706	11.14128044
	5	8.476402019	7.311602829
	10	26.73208747	8.974716256

Additionally, we also plotted the mean error for the two propagation models to graphically illustrate the comparison between the two propagation techniques. The following graphs demonstrate the difference between the two cases for the fifth floor of Duane Physics and the tenth Floor of JILA.

1. Fifth Floor of Duane Physics

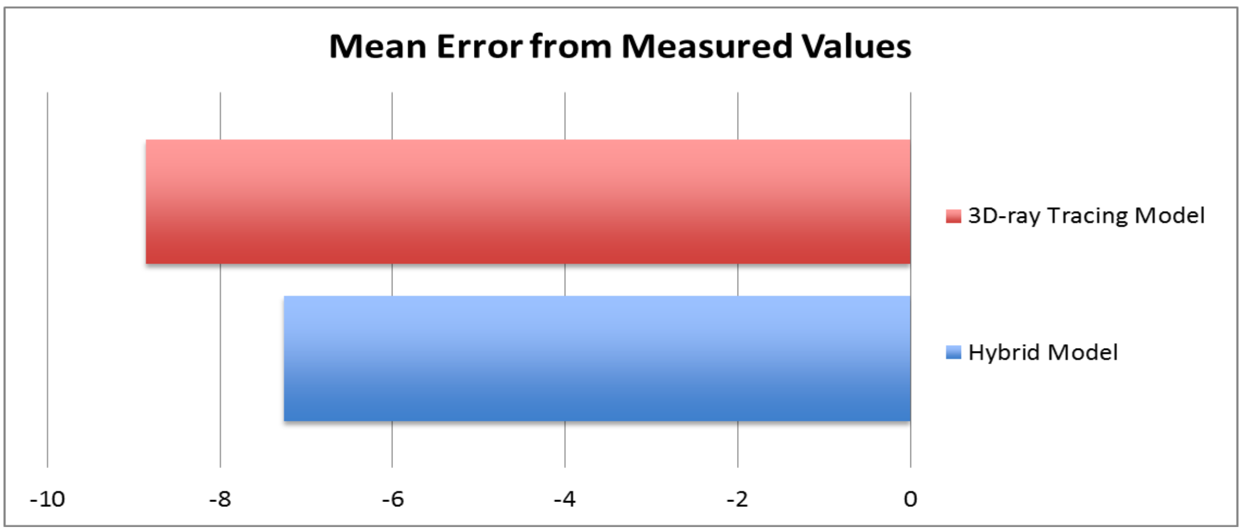

Figure 2: Calculated Mean Error in the fifth floor of Duane Physics

2. Tenth Floor of JILA

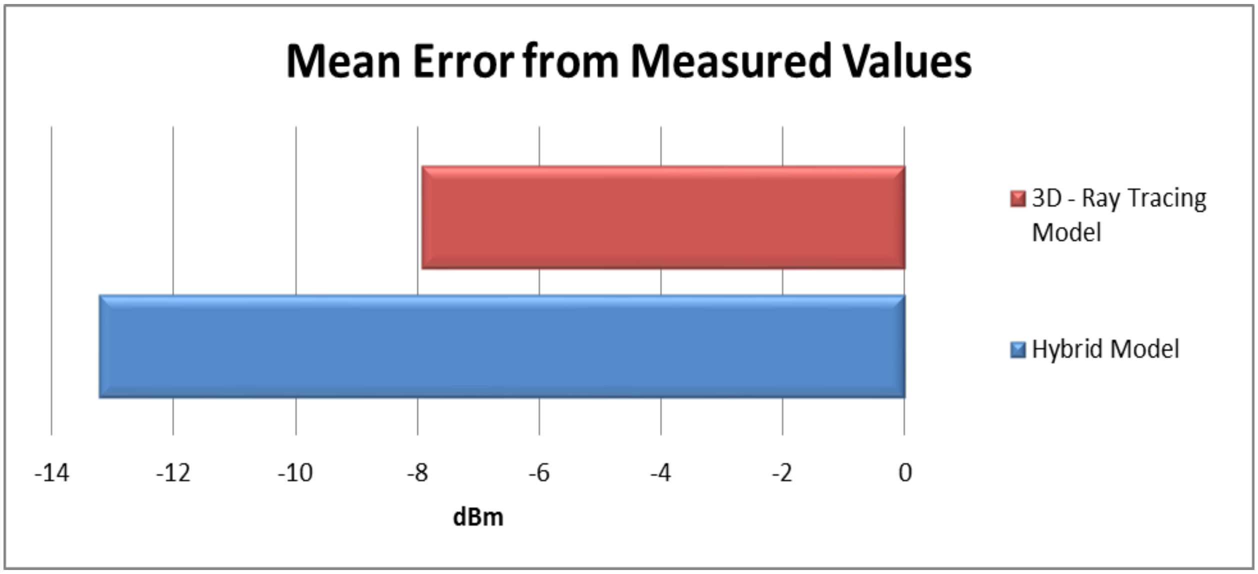

Figure 3: Calculated Mean Error in the tenth floor of JILA

As can be seen from the above figures and tables illustrating the Mean Errors and the standard deviation, performance of both the propagation models is similar. The performance of the Hybrid model was seen to be better in Duane Physics as compared to the 3D – Ray Tracing Model and the performance of 3D – Ray Tracing was better in JILA compared to the former. We can deduce from the average calculated mean error from table 2 and figures 2 and 3 that it is inconclusive to decide the better propagation models among the two.

7. Conclusion

From our route studies, area studies and calculations, we can conclude that it is difficult to choose one propagation model over the other. There are some characteristics of the presented propagation models which makes one better than the other. Some of these are listed below:

1. Scalability:

The 3D – Ray Tracing model is not scalable for large studies where the base station is far from the building of interest. There is an exponential growth in processing time as you increase the scale of the study. Although, like in our case, the 5-minute run time for this simple Pico cell case seems reasonable, it will not scale well from a macro-cell to a building. Also, the 3D - Ray Tracing requires 3D building data (not the floor plans, just the building envelope) for all the buildings that would lie between the Base station and the building of interest; this is not cost effective because the 3D building data is expensive and not readily available.

The hybrid model is much more scalable and it is more of a linear growth in processing time as the scale of the study increases. Also, the hybrid model does not require 3D building data for all of the other intermediate buildings between the transmitter and the receiver; it can take advantage of clutter data which is much cheaper and readily available.

2. Current problems with hybrid model:

The direct path nature of the hybrid model does not account for rays coming in from other directions. Ideas to deal with this issue without performing Ray Tracing would be to improve the boundary condition method between the outdoor model and indoor model, i.e. the external wall of the building. The model could also be improved by adding a simple reflection component to the indoor portion of the model.

The future scope for this project would be testing the proposed research method in a macro-cell scenario where the base station is 2-5 miles from the building of interest. Based on the suggested improvements in the Hybrid Propagation Model, we should re-examine the accuracy and performance of the model taking into consideration the data analyzed in this research project.

Acknowledgment

Firstly, with deepest appreciation, we would like to thank EDX Wireless for providing us with the chance to work on this project. Over the course of this project, we were exposed to various parameters that a Wireless Company would consider while designing and deploying their network. It was enlightening to work on SignalPro where we were able to tweak different parameters, including those which were not a part of this project, just to check the brute strength of the software.

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