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A Collective Statistical Analysis of Outdoor Path Loss Models

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ABSTRACT

This study encompasses nine path loss models (Erceg-Greenstein, Green-Obaidat, COST Hata, Hata Urban, Hata Rural, Hata Suburban, SUI, Egli and ECC-33) which were programmed on Python and studied for their results in an urban architecture (translated by higher attenuation variables) at 950 MHz and 1800 MHz. The results obtained showed that increasing the transmission antenna height with the increasing distance not only lowers down the path loss readings, but also shows that the standard deviation between the results of studied path loss models increases with the increasing transmission antenna height and increasing distance at both 950 MHz and 1800 MHz systems, especially when transmission antenna height crosses the GSM standard of 40 meters and cell-radius exceeds the limit of 20 kilometers. Moreover, it is also observed that at both 950 MHz and 1800 MHz, the path loss readings of all the models disperse from their collective mean between 1 and 10 Km, but tend converge afterwards (i.e. from 10 to 40 Km and onwards) towards their mean, which indicates that path loss readings of the urban models tend to follow either a single convergence point on large distances or reach their maximum threshold level (a level from which their readings cannot exceed or differ from each other significantly).

Index Terms

Path Loss Models; Outdoor Path Loss; Statistical Analysis

INTRODUCTION

The concept of path loss induction within outdoor cellular networks has been studied for decades. All of its major constituents and relationships with electromagnetic wave dissemination process have been studied under different distinct models, which either represent a deterministic or empirical or probabilistic way of predicting path losses over a range of distances, given different antennae heights and terrain (attenuation) constants. In more precise terms, the study of path loss mode has either been done on the area of correcting the reading errors given by different models, or for the purpose of deriving an entirely new model by the combination of two or more models, but there has been a little focus on identifying the mutual relationship that these models share between each other. It is true that all these models share their base as FRIIS model equation for free space path loss modeling, but their evolution and current form is the result of extensive research that has been done independently by their formulators in different cities, under distinct set of parameters. However, evaluating their results in a collective and cohesive manner gives out some interesting observations about the collective inferences shared by these modeling equations.

1. OBJECTIVE

To identify a relationship between different path loss models in an outdoor cellular network setting on the basis of variable physical parameters working under a pre-defined band of carrier frequencies. After having the readings under our designated sets of parameters, a statistical evaluation will be carried out to synthesize and summarize the recorded observations.

2. STUDY BACKGROUND

Path loss modeling in urban outdoor areas has found a tremendous boost since the outdoor wireless network optimization has emerged as one of the foremost problems in network planning and management. In the specific domain of cellular networks, this area of study has provided a great insight of how site planners should select their infrastructure parameters in order to provide maximum uptime and minimum losses within the transmitted data. Earlier researches have shown that the model developed by COST HATA and Stanford University Interim (SUI) models provided the most accurate (rounded) results so far in the general urban areas i.e. near to the original observation of signal path loss in different urban architectures [1]. However, this has also been addressed that these models were developed independently (in different cities and different instances of time) and their formulators share nothing but the root equation (i.e. FRIIS free space path loss calculation equation) in the models they developed. Given that, if these models have their results identical to each other, there should be a mutual relationship that is still undiscovered between these models. Such a relationship cannot be unleashed until a collective and detailed statistical analysis of their results is performed.

In terms of collective analysis, researchers in the past have adapted different approaches. For instance, the approach of collective analysis of path loss readings under conventional frequency domains taken forward by Sharma et al. (2010) remains the most widespread and commonly followed approach in the evaluation of these path loss models [1]. The second most prevalent approach is to develop an entirely new model equation for a specific wireless system (CDMA) by the collective processing of data obtained by any combination of these models, as demonstrated by Pey & Mardeni (2010) in their ground-breaking work [2]. Another similar approach has recently been adapted by Sharma & Singh (2011) who tried building a relationship between path loss readings of different models and realistic QoS within the studied cellular network under the urban architecture [3]. In addition to this, researches have started following a trend of associating any path loss model to a specific site or a system – which has created a categorization of statistical and site-specific models within these propagation prediction mechanisms [4]. However, although these approaches stand valid at their specific perspectives (and have contributed path loss predicting models under a bunch of pre-defined physical and logical parameters (corresponding to industry norms). constructively) but still there is no insight on the issue of how the readings of these path loss models amazingly react along with each other in a generalized, high-attenuation encompassing urban areas. For instance, if the results obtained from two models in urban settings go up and down simultaneously with changing parameters, or follow a specific trajectory on the decibel chart with variable distance and Tx/Rx antennae height factors, it is not just the matter that these models are built on the same root equation. This makes it evident that although different models yield different results, but their collective representation highlights a single phenomenon which cannot be generalized until its base constituents are studied properly. Furthermore, if their results are statistically evaluated for the purpose of trend identification, some very reflective results can be obtained. This is the background motivation and rationale for this study, which is set to evaluate different urban

2. METHODOLOGY

For experimenting with the above mentioned hypothetical assertion, two major parameter sets based on the operating frequencies of 950 and 1800 MHz were developed to be tested within GSM architecture operating within an urban area (with attenuation factors raised to their maximum values). Following major and commonly known path loss models were implemented as a part of this study:

No.	Model
1.	COST-HATA Model
2.	HATA (Urban) Model
3.	HATA (Suburban) Model
4.	HATA (Rural) Model
5.	Erceg-Greenstein Model
6.	Green-Obaidat Model
7.	Stanford University Interim (SUI) Model
8.	ECC-33 Model
9.	Egli Model

These models were selected on the basis of similarities of their results with each other in urban settings, which is a valid parameter of selection of models (as practiced by [3] and [4]). Further, the operating frequencies are selected on the basis of two major reasons:

a. The GSM band of frequencies (our selected subject of study) is widely based on these two types of frequencies, and in most of the countries, the operating carrier frequency band for GSM-based carriers is allocated to be between 900-950 MHz band [5] and 1800 to 1820 bands [6].

b. The selected models employed within this study are also valid on these operating frequencies, which is one of the reasons of selecting these particular path loss models from the pool of a variety of path loss models for urban areas [5][8][9] [10][11].

Moving forward, the experiment was conducted by increasing the base station height (by the units of tens) with each operating frequency up to 60m in order to identify the results that are provided with each base station antenna height, while keeping the mobile station antenna height as fixed and static on the ground. This depicts a scenario that the mobile station is roaming on the ground under the footage of a cell-site while antenna height (m) is playing its role in determining the path loss at mobile station's end. This methodology was repeated over increasing distance points (in Km) under two selected operating frequencies, which resulted 10 sets of results i.e. 5 for each operating frequency, with each having a different base station antenna height. Through the analysis of these sets of frequencies, some very important trends within the readings along with the basic relationships between these models were identified.

3. ANALYSIS TECHNIQUE

The obtained path loss readings are to be kept in the units of decibels (dB) which is the actual logarithmic unit used to represent the received power in telecommunication systems. These readings are categorized into ten tables, representing the different parameters employed in the experimentation process. The analysis of the readings is carried out in a way that for each distance point, a descriptive statistical test was (including mean, variance, standard deviation and kurtosis) conducted for the readings of all the models. In addition to these analyses settings, a range analysis is conducted on every reading of each path loss at a pre-defined distance point, and all these range readings are finally averaged to yield two values for two operating frequencies.

A. Application

The selected path loss models were programmed and simulated from ground on Python 2.7 and their illustrations were generated through open-source Python libraries like NumPy, SimPy and MatPlotLib.

B. Parameter Sets

TABLE I

Parameter Set A

Parameter Set A					
***f* (MHz)**	**BSH (m)**	**MSH (m)**	**Gain (dB)**	**Att.**	**Distance Points (Km)**
950	20	3	1	Urban	1,2,5,10,20,40
950	30	3	1	Urban	1,2,5,10,20,40
950	40	3	1	Urban	1,2,5,10,20,40
950	50	3	1	Urban	1,2,5,10,20,40
950	60	3	1	Urban	1,2,5,10,20,40

In the table above, f (MHz) refers to frequency in MHz, BSH refers to base station height in meters, MSH refers to mobile station height in meters, Gain refers to respective gains of transmission and receiver antennae in dB, Att. refers to attenuation which is set to urban levels (i.e. maximum) and Distance Points refer to the distance points in Km on which the readings were taken.

TABLE 2

Parameter Set B

Parameter Set B					
***f* (MHz)**	**BSH (m)**	**MSH (m)**	**Gain (dB)**	**Att.**	**Distance Points (Km)**
1800	20	3	1	Urban	1,2,5,10,20,40
1800	30	3	1	Urban	1,2,5,10,20,40
1800	40	3	1	Urban	1,2,5,10,20,40

1800	50	3	1	Urban	1,2,5,10,20,40
1800	60	3	1	Urban	1,2,5,10,20,40

In the table above, f (MHz) refers to frequency in MHz, BSH refers to base station height in meters, MSH refers to mobile station height in meters, Gain refers to respective gains of transmission and receiver antennae in dB, Att. refers to attenuation which is set to urban levels (i.e. maximum) and Distance Points refer to the distance points in Km on which the readings were taken.

II. RESULTS & ANALYSIS

The results obtained after analysis revealed some interesting patterns between the readings of these models:

A. *Mean Path Loss - Parameter Sets A & B:*

Under the both parameters, it is observed that the mean (or average) path loss readings of all these models tend to increase with the increase in distance while transmission antenna height is fixed (it is a widely known fact). However, it is observed that once the transmission antenna height starts increasing, the mean or average path loss reading for all the models also decreases (as shown in Fig. 1 and Fig. 2).

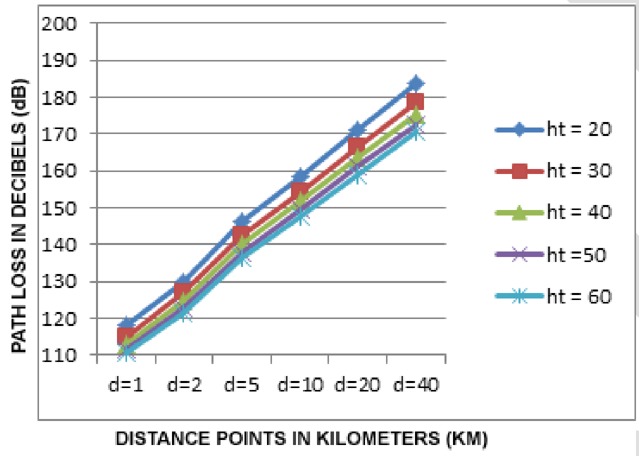

Fig. 1. ht (corresponding to BSH) refers to the height of transmission antenna in meters. It can be observed that increasing the base station height decreases the mean path loss at 950 MHz for all the models at the given distance points.

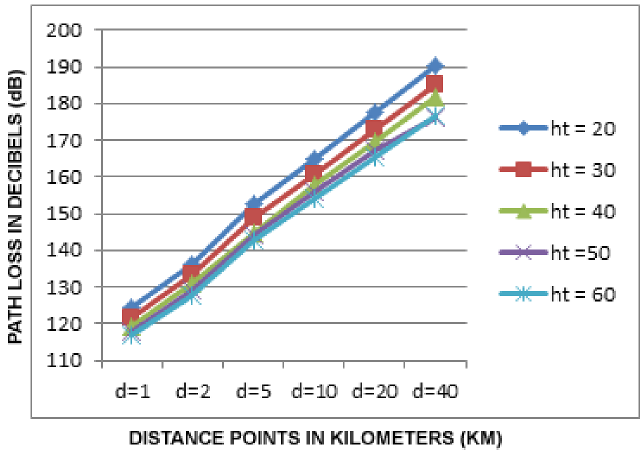

Fig. 2. ht (corresponding to BSH) refers to the height of transmission antenna in meters. It can be observed that increasing the base station height decreases the mean path loss at 1800 MHz for all the models at the given distance points.

B. *Standard Path Loss Deviation – Parameter Sets A & B:*

At 950 MHz, it is observed that once the distance increases between transmitter and receiver in an urban symmetry, the standard deviation of all the studied path loss model reading tend to converge towards their collective mean (which in practical indicates that all the studied path loss models at 950 MHz produce identical results at near distance points). On the other hand, once the transmission antenna height is increased, the standard path loss deviation also increases for all the path loss models at farther distance points, which actually indicates that increasing separation between transmitter-receiver and increasing transmission antenna height increases the difference between individual path loss reading of a single model and the mean (or average) of all the path loss model readings at every particular distance point. This phenomenon can be observed in the Fig. 3:

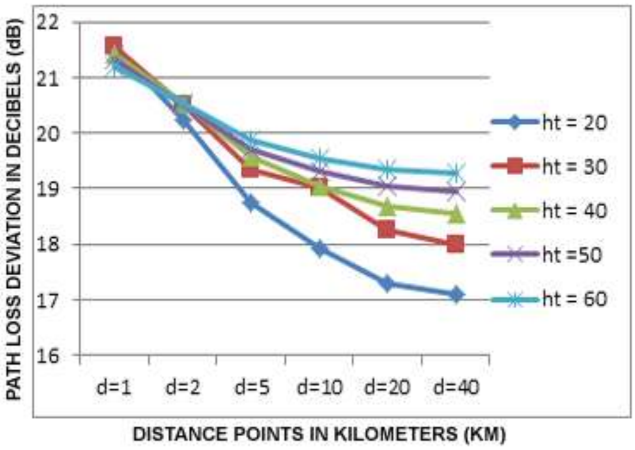

Fig. 3. It can be seen that the standard path loss deviation is decreasing with the increasing separation between transmitter and receiver at 950 MHz. Moreover, this deviation phenomenon is increasing as ht (transmission antenna height corresponding to BSH) increases.

A similar phenomenon is also observed within the standard path loss deviation calculation of parameter set B (ie. at 1800 MHz), except that there are significant fluctuations at points (d=40 Km, ht=50m) and (d=40 Km and ht=60m) reflected by an abrupt increase in the standard deviation of all the path loss models on a collective basis. What this indicates is the verification of the concept that increasing the transmission frequency decreases the shadow of a cell site, while also decreases the transmission power, giving leverage to the path loss [12]. This can be identified as the threshold of a transmission and reception architecture under our developed settings, where at a certain point of distance, increased antenna height factor becomes indifferent against the incurring loss within the signal power (look at Table II).

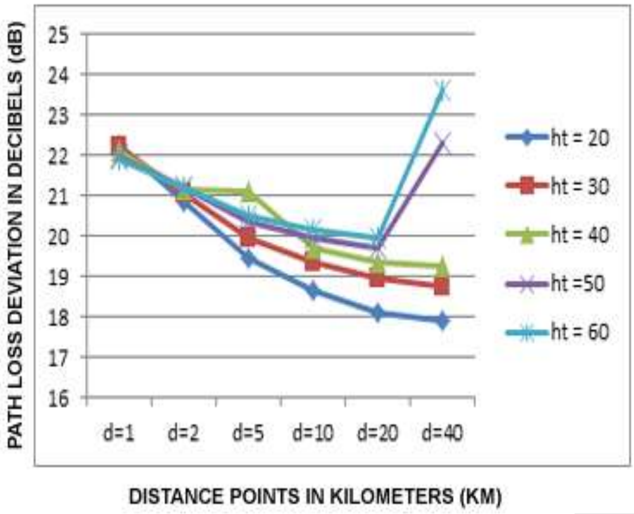

Fig. 4. It can be seen that the standard path loss deviation is decreasing with the increasing separation between transmitter and receiver at 1800 MHz. However, increasing transmission antenna height is contributing positively in increasing the deviation of loss readings from the average.

C. Kurtosis Analysis of Path Loss Readings- Parameter A &B:

The kurtosis readings of all the path loss models indicate that the under both the Parameter Sets A and B, increased antenna height with increased transmitter-receiver separation:

Decreases the kurtosis readings at from d=1 Km to d=10 Km – forming a platykurtic distribution which reflects that the data readings tend to form a dispersion from their collective mean value between 0 and 10 Km points at both 950 and 1800 MHz. In practical terms, this phenomenon indicates that under a certain initial range of distance (i.e. 0-10 Km) the increased antenna height factor contributes in resulting varied readings from 0 to 10 Km at both 950/1800 MHz based cell sites.

Increases the kurtosis readings from d=10 to d=40 Km – forming a leptokurtic distribution which reflects that data readings tend to form a convergence or peak around their mean (or tending to get closer to their mean) between 10 to 40 Km points at 950/1800 MHz. In more practical terms, this indicates that after a certain initial distance point i.e. after 10th Km the increased antenna height factor contributes in resulting converged and identical readings within both 950 and 1800 MHz based cell sites.

This opens up another interesting topic: Is there something common between parameters over which these model equations were initially developed? The answer to this query lies within the fact that path loss models tend to follow a converged trajectory after a certain distance point, which means that even if the transmission antenna height is kept constant, the readings from different urban path loss models will tend to become identical to each other with increasing distance, and at a certain impractical distance point, will become converged. This is the indication that path loss models and their readings also possess a certain upper-bound, which can be observed by following a signal path loss over a larger range of large distance.

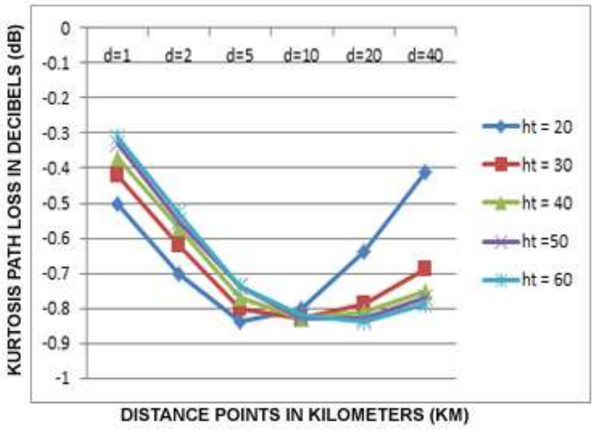

Fig. 4. Kurtosis analysis of path loss readings for Parameter Set A

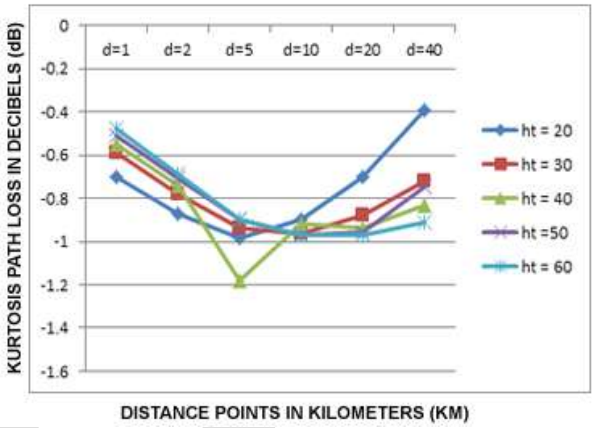

Fig. 4. Kurtosis analysis of path loss readings for Parameter Set A

D. Range Analysis – Parameter Set A & B:

In order to further investigate the collective readings of studied path loss models, their range was calculated at each distance point and finally averaged to reflect a single average separation between the readings at d=1 Km and d=40 Km under both sets of parameters. The result obtained from this procedure yielded an observation that increasing the transmission frequency of the system decreases the average difference between the readings of the path loss models i.e. the difference between path loss reading at d=1 Km and d=40 Km at f1 is larger than difference obtained at f2, given that f2 is greater than f1 (f2>f1).

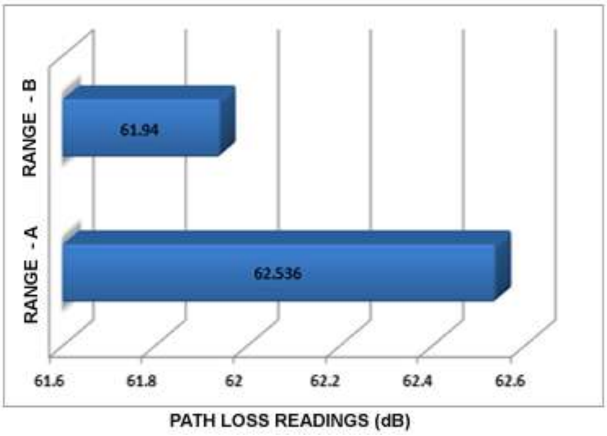

Fig. 5. Difference between the averaged path loss ranges for Parameter Set A (PA) & Parameter Set B (PB)

III. CONCLUSION

There were nine path loss models which were studied for their results in an urban architecture (translated by higher attenuation variables). The results obtained showed that increasing the transmission antenna height with the increasing distance not only lowers down the path loss readings, but also shows that the standard deviation between the results of studied path loss models increases with the increasing transmission antenna height and increasing distance at both 950 MHz and 1800 MHz systems, especially when transmission antenna height crosses the GSM standard of 40 meters and cell-radius exceeds the limit of 20 kilometers. Moreover, it is also observed that at both 950 MHz and 1800 MHz, the path loss readings of all the models disperse from their collective mean between 1 and 10 Km, but tend converge afterwards (i.e. from 10 to 40 Km and onwards) towards their mean, which indicates that path loss readings of the urban models tend to follow either a single convergence point on large distances or reach their maximum threshold level (a level from which their readings cannot exceed or differ from each other significantly).

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