Prediction Methods for Long Term Evolution (LTE) Advanced Network at 2.4 GHz, 2.6 GHz and 3.5 GHz

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ABSTRACT
In this paper, a comprehensive review of the propagation prediction models for LTE Advanced is presented and computation of path loss for different terrains rural, dense urban, suburban and open terrain has been carried using MATLAB based simulations for various prediction techniques such as COST-231 Hata model, COST Walfish-Ikegami method, SUI model and Egli model for broadband and mobile services. The paper studies the path loss models of the wideband channels at 2.3GHz, 2.6GHz and 3.5 GHz for the LTE-Advanced Network.

General Terms
Prediction Methods

Keywords
LTE, Path loss, Propagation models.

1. INTRODUCTION
The Long Term Evolution (LTE) is the latest step in moving forward from the cellular 3rd Generation (3G) to 4th Generation (4G) services. LTE Advanced is a mobile communication standard, formally submitted as a candidate 4G system to ITU-T in late 2009, was approved into ITU, International Telecommunications Union, IMT-Advanced and was finalized by 3GPP in March 2011 [1]. It is standardized by the 3rd Generation Partnership Project (3GPP) as a major enhancement of the Long Term Evolution (LTE) standard. The first release of LTE does not meet the requirements for 4G such as peak data rates up to 1 Gb/s. The ITU has invited the submission of candidate Radio Interface Technologies (RITs) following their requirements in a circular letter, 3GPP Technical Report (TR) 36.913, "Requirements for Further Advancements for E-UTRA (LTE-Advanced)" [2]. An LTE terminal should be able to work in an LTE-Advanced network and vice versa. Any exceptions will be considered by 3GPP., Consideration of recent World Radio communication Conference (WRC-07) decisions regarding frequency bands to ensure that LTE-Advanced accommodates the geographically available spectrum for channels above 20 MHz. Also, specifications must recognize those parts of the world in which wideband channels are not available. One of the important LTE Advanced benefits is the ability to take advantage of advanced topology networks; optimized heterogeneous networks with a mix of macrocells with low power nodes such as picocells, femtocells and new relay nodes. The next significant performance leap in wireless networks will come from making the most of topology, and brings the network closer to the user by adding many of these low power nodes. LTE Advanced further improves the capacity and coverage, and ensures user fairness. LTE Advanced also introduces multicarrier to be able to use ultra wide bandwidth, up to 100 MHz of spectrum supporting very high data rates. In the research phase many proposals have been studied as candidates for LTE Advance technologies. The proposals could roughly be categorized into [3].

1. Support for relay node base stations
2. Coordinated multipoint (CoMP) transmission and reception
3. UE Dual TX antenna solutions for SU-MIMO and diversity MIMO
4. Scalable system bandwidth exceeding 20 MHz, up to 100 MHz
5. Carrier aggregation of contiguous and non-contiguous spectrum allocations
6. Local area optimization of air interface
7. Nomadic / Local Area network and mobility solutions
8. Flexible spectrum usage
9. Cognitive radio
10. Automatic and autonomous network configuration and operation
11. Support of autonomous network and device test, measurement tied to network management and optimization
12. Enhanced precoding and forward error correction
13. Interference management and suppression
14. Asymmetric bandwidth assignment for FDD
15. Hybrid OFDMA and SC-FDMA in uplink
16. UL/DL inter eNB coordinated MIMO
17. SONs, Self Organized Networks methodologies
18. Multiple carrier spectrum access.

Within the range of system development, LTE-Advanced and WiMAX-2, can use up to 8x8 MIMO and 128 QAM. LTE-Advanced provides almost 3.3 Gbit peak download rates per sector of the base station under ideal conditions. Advanced network architectures combined with distributed and collaborative smart antenna technologies provide several years road map of commercial enhancements. A summary of a study carried out in 3GPP can be found in TR36.912.[4] Realistic modeling of propagation characteristics is essential for the development of LTE, both for predicting achievable performance in typical deployment scenarios and for network planning. Before implementing designs and confirming planning of wireless communication systems, accurate propagation characteristics of the environment should be known.

As the demand for mobile communication services increases, deterministic propagation prediction techniques play an important role in the optimization of the coverage and the efficient use of the available resources [5]. The ability to predict the minimum power necessary to transmit from a given base station at a given frequency, and to provide an acceptable quality of coverage over a predetermined service area, and to estimate the effect of such transmissions on existing adjacent services, is crucial for the improvement of frequency reuse and the implementation of band sharing schemes between different services and for the success of cellular systems. There is a need for a better understanding of the influence of the different urban and terrain factors on the mobile radio signal and its variability.

Development of reliable propagation models and the availability of the associated simulation software tools would be absolutely necessary for the successful implementation of the future terrestrial wireless systems and also for their integration with other technologies. Accurate propagation models will help in using the rather congested frequency spectrum more efficiently, in planning more effective radio networks, and in implementing cost effective solutions for a desirable and user specific communication coverage pattern. This paper reviews all the important propagation models of relevance to LTE. In this paper, a comparison is made between different proposed propagation models that would be used for 4G wireless system for different transmitting antenna heights, like Egli Mode [6l, Stanford University Interim (SUI) model [7], COST-231 Hata model [8]-[10], COST Walfisch-Ikegami model [11]] and computation of path loss due to specific terrain and clutter environment has been carried using MATLAB based simulations for various prediction.

In Section II, details of different propagation models have been provided. In Section III, we have analyzed and compared the existing path-loss models. Conclusions are presented in Section IV.

2. PROPAGATION PATH LOSS MODELS

2.1 Egli Model

The Egli model [6] is typically suitable for cellular communication scenarios where one antenna is fixed and another is mobile. The model is applicable to scenarios where the transmission has to go over an irregular terrain. However, the model does not take into account travel through some vegetative obstruction, such as trees or shrubbery. The model is typically applied to VHF and UHF spectrum transmissions. The path loss is calculated as

$$PL(dB) = 0.668 * G_B G_M \left[\frac{h_B}{d} h_M \right]^2 \left[\frac{40}{f} \right]^2 \quad (1)$$

In this model, GB is the gain of the BS antenna, GM is the gain of the CPE antenna, hB is the height of the BS antenna from ground level, hM is the height of the CPE, d is the receiver distance from the BS and f is the operating frequency.

2.2 SUI Model

The SUI model was developed under the Institute of Electrical and Electronics Engineers (IEEE) 802.16 working group for prediction of path loss in urban, suburban and rural environments [7]. The applicability of this model in the higher frequency has not been validated. However, due to the availability of correction factors for the operating frequency, this model is selected for this study. The path loss in SUI mode [7] is calculated using (2).

$$L = A + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + s \quad \text{for } d > d_0 \quad (2)$$

where, d is the distance between the base station and the receiver antenna in metres, d0 = 100 m and s is a lognormal distributed factor that is used to account for the shadow fading owing to trees and other clutter and has a value between 8.2 dB and 10.6 dB . The other parameters are defined as,

$$A = 20\log_{10}\left(\frac{4\Pi d_0}{\lambda}\right) \quad (3)$$

$$\gamma = a - bh_b + c/h_b \quad (4)$$

where, the parameter hb is the base station height above ground in meters and should be between 10 m and 80 m .The constants used for a, b and c are given in Table I.

Table I SUI Model Parameter

Model Parameter	Terrain type A	Terrain type B	Terrain type C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

2.3 COST-231 Hata Model

This model has been developed based on experimental measurements conducted by Okumura in Tokyo (Japan) region [8], [9].

Experimental formula for propagation path loss L in dB by Hata [10]

$$L\{urban\,area\} = 69.55 + 26.16\log_{10} f - 13.82\log_{10} h_b - c(h_m) + (44.9 - 6.55\log_{10} h_b)\log_{10} d \quad (5)$$

where f is the frequency (in MHz) from 150 MHz to 1500 MHz, hb is the effective transmitter (base station) antenna height (in meters) ranging from 30m to 200m, hm is the effective receiver antenna height (in meters) ranging from 1m to 10m, d is the T-R separation distance (in km) ranging from 1 to 10 km, and $c(h_m)$ is the correction factor depending on the mobile station antenna height which is function of the size of the coverage area. For small to medium sized city, the mobile antenna correction factor is defined as

$$c(h_m) = (1.1\log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8)dB \quad (6)$$

and for a large city, the correction factor $c(h_m)$ is defined as

$$c\ (h_m) = 8.29(\log_{10} 1.54h_m)^2 - 1.1 \quad for\ f \leq 300\,MHz \quad (7)$$

$$c\ (h_m) = 3.2(\log_{10} 11.75h_m)^2 - 4.97 \quad for\ f \geq 300\,MHz \quad (8)$$

The path losses L_S and L_O in dB for suburban and open areas are given in equations (9) and (10) respectively.

$$L_S = L\ \{urban\,area\} - 2\{\log_{10}(f\ /28)\ \}^2 - 5.4 \quad (9)$$

$$L_O = L\{urban\,area\} - 4.78\{(\log_{10} f\ )^2\} + 18.33\log_{10} f - 40.94 \quad (10)$$

This model is well suited for large cell mobile systems, but not personal communications systems (PCS) which have cell on the order of 1 km radius.

2.4 COST Walfisch-Ikegami Model

Walfisch-Bertoni method is combined with the Ikegami model [11], to improve path loss estimation through the inclusion of more data. Four factors height of buildings, width of roads, building separation, road orientation with respect to the LOS path are included.

In the non-LOS case the basic transmission loss comprises the free space path loss L, the multiple screen diffraction loss Lmsd and the rooftop to street diffraction and scatter loss Lrts . Thus the path loss L in non LOS is defined as

$$L = \begin{cases} L + L_{rts} + L_{msd} & L_{rts} + L_{msd} > 0 \\ L & L_{rts} + L_{msd} < 0 \end{cases} \qquad (11)$$

The determination of Lrts is based on the principle given in the Ikegami model, but with a different street orientation function .The values of Lrts are as follows.

$$L_{rts} = -16.9 - 10\log_{10} w + 10\log_{10} f_{MHz} + 20\log_{10}(h - h_m) + L_{ori} \qquad (12)$$

where w, h and hm are gap between buildings, height of building and height of mobile stations respectively.

$$L_{ori} = \begin{cases} -10 + 0.354\psi & 0^0 \le \psi < 35^0 \\ 2.5 + 0.075(\psi - 35) & 35^0 \le \psi < 55^0 \\ 4.0 - 0.114(\psi - 55) & 55^0 \le \psi < 90^0 \end{cases} \qquad (13)$$

where Lori is a factor which has been estimated from only a small number of measurements, ψ is street orientation angle. The multiple screen diffraction loss was estimated by Walfisch and Bertoni for the case when the base station antenna is above the rooftops i.e. hb>h. This has also been extended by COST to the case when the antenna is below rooftop height, using an empirical function based on measurements. The relevant equations are

$$L_{msd} = L_{bsh} + k_a + k_d \log_{10} d_{km} + k_f \log_{10} f_{MHz} - 9\log_{10} b \qquad (14)$$

where

$$L_{bsh} = \begin{cases} -18\log_{10}[1 + (h_b - h)] & h_b > h \\ 0 & h_b \le h \end{cases} \qquad (15)$$

$$k_a = \begin{cases} 54 & h_b > h \\ 54 - 0.8(h_b - h) & h_b \le h \text{ and } d_{km} \ge 0.5km \\ 54 - 0.8(h_b - h)\dfrac{d}{0.5} & h_b \le h \text{ and } d_{km} < 0.5km \end{cases} \qquad (16)$$

$$k_d = \begin{cases} 18 & h_b > h \\ 18 - 15\dfrac{(h_b - h)}{h} & h_b \le h \end{cases} \qquad (17)$$

$$k_f = -4 + \begin{cases} 0.7\left(\dfrac{f_{MHz}}{925} - 1\right) & \text{for medium sized cities and suburban} \\ & \text{centres with medium tree density} \\ 1.5\left(\dfrac{f_{MHz}}{925} - 1\right) & \text{for metropolitan centres} \end{cases} \qquad (18)$$

The term ka represents the increase in path loss when the base station antenna is below rooftop height. The term kd and kf allow for the dependence of the diffraction loss on range and frequency, respectively.

Table II shows the values of different parameters taken for calculating the path loss values for different propagation models.

Table II. Details of Simulation Parameters

S. No.	Details	
1.	Height of receiving antenna	3m
2.	Transmitted power	40dBm
3.	Average Height of building	25m
4.	Average street width	15m
5.	Average separation between buildings	30m
6.	Street orientation angle	90 degrees

3. PATH LOSS ANALYSIS

Fig.s 1 to 3 show the comparison of path loss values for COST-231 Hata model at frequencies 2300 MHz, 2600 MHz and 3500 MHz for different terrains. In Fig. 1, close to transmitter path losses varied from 100-120 dB and at distances beyond 500 m, path loss was confined between 110-160 dB. It is observed that as frequency increases path loss values are decreasing in proportion.

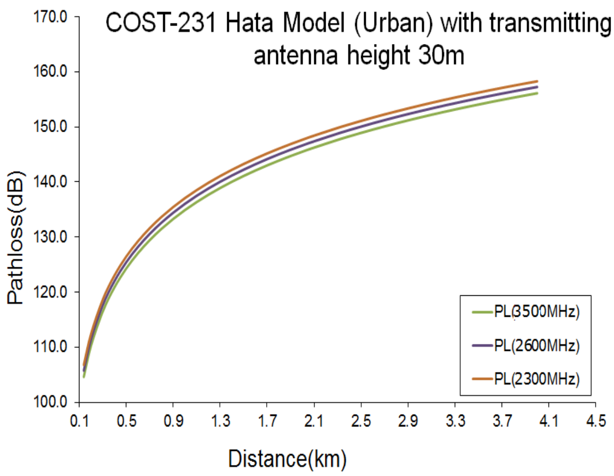

Fig.1: Comparison of path losses for COST-231 Hata model (Urban) at different frequencies

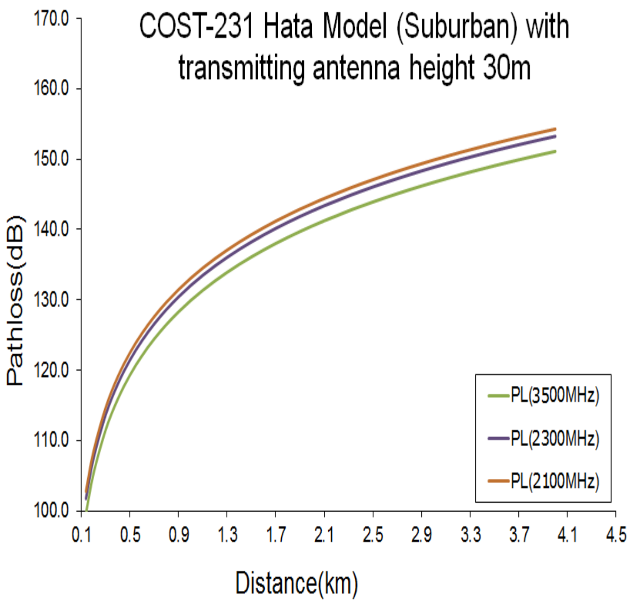

Fig. 2: Comparison of path losses for COST-231 Hata model (Suburban) at different frequencies

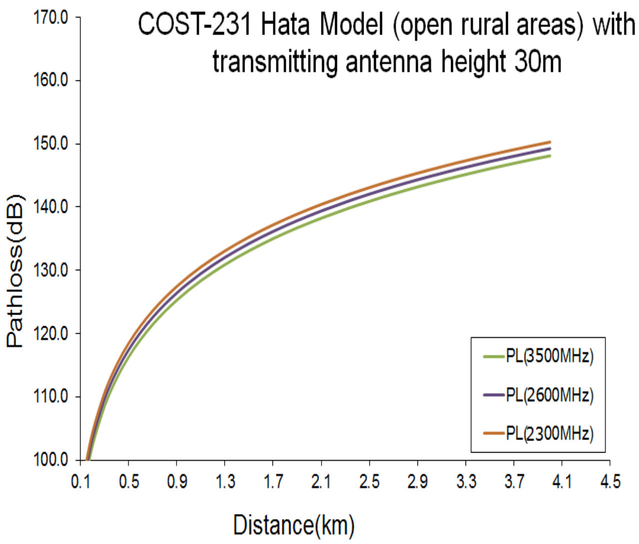

Fig.3. Comparison of path losses for COST-231 Hata model (open rural) at different frequencies

It is observed from the Fig. 4 that path loss values are less for suburban and open rural areas as compared with urban scenario. In Fig. 5, COST-WI model is compared at frequencies 2300 MHz, 2600 MHz ans 3500 MHz for urban environment and It can be observed that COST-WI model shows more path loss values as compared to COST-231 Hata model (Fig. 1) for the same distances. Fig. 6 shows the path loss values of different models at 2300 MHz. It is observed that COST-WI and COST-231 Hata methods have least path loss values.

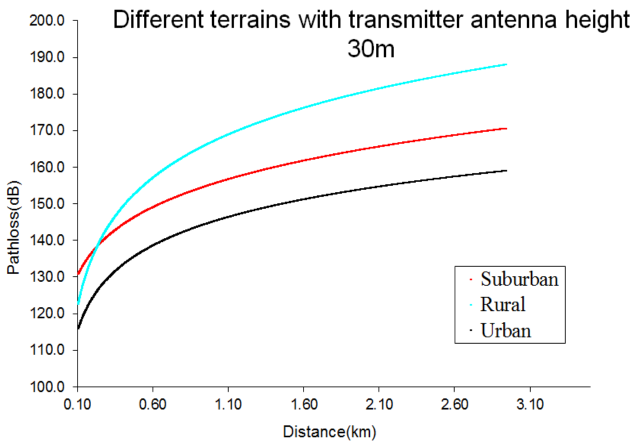

Fig.4: Comparison of path losses for COST-231 Hata model for different terrains

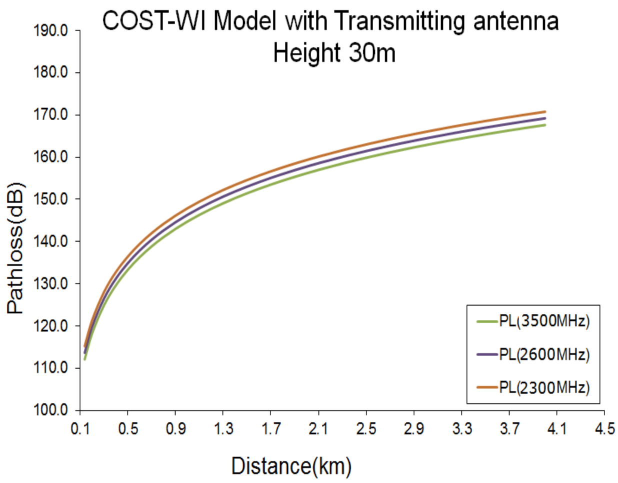

Fig.5: Comparison of path losses for COST-WI model (Urban) at different frequencies

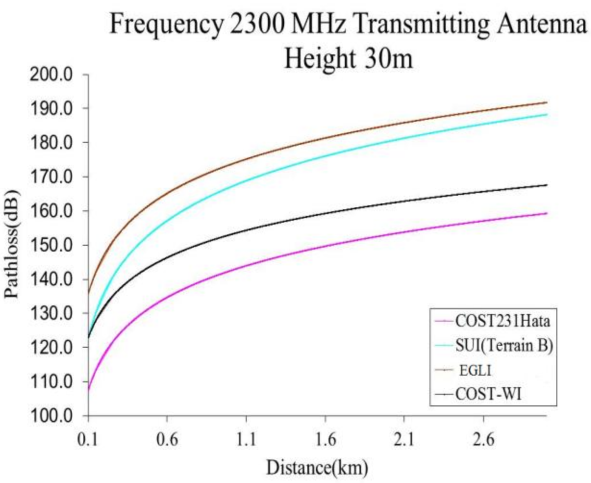

Fig.6:Comparison of path losses for different propagation model

In Table III the corresponding error statistics in terms of mean prediction error, μ, and the standard deviation of the prediction errors, σ, are given for each model for different frequencies. An examination of the table III shows that path loss exponents from SUI method are around 4.0 for all base stations and around 3.3

for Egli model considering unit gain transmitting and mobile antennas. Mean prediction error of COST-WI model and COST-231 Hata is less than mean prediction error of SUI model and ITU-R(NLOS) model. Abhayawardana etal. [12] observed that SUI model showed large mean path loss prediction errors. They felt that it is highly recommended for urban environments and should be applicable for lightly built European cities. Mardeni [13] based on 2.3GHz measurements in the suburban and open urban environments in the Malaysia observed that out of SUI, COST-231 Hata, Egli, COST-231 Hata showed closest agreement with observations in terms of path loss exponent prediction and standard deviation error analysis. With the increase in frequencies, error's standard deviation decreases from 0.8 to 0.9 for different prediction methods

4. CONCLUSION

A comprehensive review of the propagation prediction models for 4G wireless communication systems is presented and computation of path loss values due to specific terrain and clutter environment has been carried using MATLAB based simulations for various prediction techniques such as COST-231 Hata model, COST Walfish-Ikegami method, SUI model and Egli model for broadband and mobile services. A comparison of different prediction methods showed that COST-231 Hata's prediction method gave least path loss. The advantage of this method lies in its adaptability to different environments by incorporating correction factors for various environments. The prediction errors of the SUI and Egli models are considerably higher than those of the COST-231Hata and COST Walfisch–Ikegami models.

5. REFERENCES

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Table III. Comparison of Statistical Parameters

Frequency (GHz)	COST-231HATA			COST-WI			SUI			EGLI		
	n	μ	σ	n	μ	σ	n	μ	σ	n	μ	σ
2.3	3.5	-0.2	6.7	3.2	-12.9	6.8	4.3	-23.3	7.1	3.3	-28.4	6.8
2.6	3.5	4.9	5.9	3.3	-6.7	5.9	4.4	-20.1	6.2	3.3	-26.6	6.0
3.5	3.5	2.8	4.3	3.2	-5.7	5.6	4.4	-18.2	5.6	3.3	-20.1	5.2