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Cell Coverage Area and Link Budget Calculations in LTE System

Purnima K Sharma[1], Dinesh Sharma[1*] and Akanksha Gupta[2]

[1]ECE Department, VRSEC,Vijayawada –520007, Andhra Pradesh, India; sharma82dinesh@gmail.com
[2]ECE Department, G.E. University, Dehradun, Uttarakhand –248002, India.

Abstract

The network planning is a significant step in establishment of wireless communication system. For a wireless system the primary setup takes a lot of time for process and also very expensive. Because of this reason it uses a mathematical model before the processing of the system to avoid unknown expenses. The mathematical model calculation mainly includes path loss, link budgets etc. Radio propagation is site specific and it varies substantially depending on geography, frequency at which system will operate mobile terminal speed, interface sources and other dynamic factors. To estimate the signal coverage and to achieve a high data rates, it is very important to illustrate the radio channel through important parameters and with the help of a mathematical model. In this paper we have evaluated the cell coverage area for Long Term Evolution (LTE) technology at 1800 MHz (FDD-LTE) theoretically for different transmitting antenna heights and at different transmitting power levels. This coverage area is then compared with the practical measured coverage area i.e. practical measured path loss. The signal coverage starts within the cell, by predicting the affecting parameters on the signal power level in the uplink and downlink at the practical cases. In this paper the concentration is completely on pre-process of network planning i.e. link budgeting of LTE cellular system. This investigation can also lead the radio planner to a thorough understanding of radio wave propagation for designing mobile communication system.

Keywords: Base Transceiver Station (BTS), Coverage Area, Link Budget, Long Term Evolution (LTE), Path Loss

1. Introduction

The implementation of wireless system designing depends on the electromagnetic radio propagation characteristics. Conducting series of propagation measurements during drive test is very high in cost and also requires more time for process to determine data rates, maximum coverage area and base station locations[1]. So it is required to develop a mathematical model to calculate all these parameters before going for the establishment of a wireless system.

LTE, Long Term Evolution, is a 4G standard. UMTS and HSPA are the presiders to LTE. This LTE is well known for its high speed data and voice cellular services. Previously it is a simple 3G but with later technological development of this standard evolved into a high speed 4G standard. In this form it was referred to as LTE Advanced. Due to rapid growth in the usage of cellular devices, and this increase will only become larger and termed as «data explosion». To meet such a hungry for the increased data transmission speeds and lower latency, further developments in cellular technology are. The following are the main objectives for LTE[2,3]:

- Downlink and uplink data speed increment;
- Accessible bandwidth;
- Improvement in spectral efficiency;
- IP network; and
- Great support for multitude of user types.

LTE provides an increment in downlink speed (100Mbps) and an uplink speed (50Mbps). The accessible bandwidth is from 1 MHz to 20 MHz and supports both Frequency Division Duplex (FDD) and Time Division

**Author for correspondence*

Duplex (TDD)[4]. These data rates can be further improved by using MIMO technology at transmitter and receiver sides. The selection of an appropriate radio propagation model for LTE is of great importance. A radio propagation path loss model is useful to describe the signal behavior while it is travelling in between transmitter and receiver. There is a relation between distance from the transmitter to the receiver and the total path loss. From this relation, one can calculate the path loss and the cell range. Path loss mainly depends on many causes like the condition of environment (urban, rural, dense urban, suburban, open, forest, sea etc.), frequency at which the system operates, atmospheric conditions, indoor/outdoor and the distance between transmitter and receiver[5].

2. Coverage Area

A cellular network is a wireless radio network which is distributed over small areas called cells; each cell can be served by one fixed BTS. These cells cater radio coverage over a large land area. This network provides services to many consumers who are using mobile phones, pagers, etc., to communicate with people anywhere in the network via BTS. The cell coverage mainly depends on usual causes such as geographical conditions, propagation conditions, and on social causes such as the terrain type (urban, suburban, rural) etc. Here the eminence of radio network coverage can be calculated in terms of location probability. For that purpose it is important to predict propagation conditions as accurately as possible for the particular region. Signal propagation mainly depends on three mechanisms[6]. Those three mechanisms are as follows:

- *Reflection*. When an object in the environment which is large enough when compared to its length then a propagating EM wave in such a environment experiences reflection. These Reflections are produced from many sources like the ground surfaces, the walls and from equipments.
- *Diffraction*. When there is a unexpected obstruction in the path then the propagating EM wave diffracts from the path. Signal experiences more diffraction at sharp edges. When NLOS exist in the radio path, the diffraction occurs when wave propagates behind the obstacle.
- *Scattering*. When the signal hits the obstacle in the path which is small compared to the signal wavelength or the number of obstacles per unit is enough large compared to the signal, then the ray get scattered. In the practical field, it occurs due to small objects like foliage, lampposts and street signs especially in the city area.

Radio planner mostly uses the propagation models in two ways. They use models either developed by their own or some standard models which have predefined parameters which are general in nature. But these standard models are not as accurate as own developed models. The own developed models can give more accurate results but it takes more time for the development. That's why it is better to use the standard models to save money as well as time.

The standard models uses already existing equations which are obtained from results of several drive test measurement efforts. Some of the standard path loss models are as follows[7-10]:

(a) Free space model
(b) Cost-231 Model
(c) Ericsson Model
(d) Winner II Model
(e) ECC-33 Model
(f) SUI Model

These propagation models are used for the evaluation of the EM field strength for the purpose of wireless network planning during exploratory deployment. These models are empirical. Using Path loss calculations we can determine the cell ranges. Usually we can define three cell ranges: Large cells, small cells and micro cells. Large cells radius is from 1 km and normally it go beyond 3 km. Small cells radius is from 0.3 km to 1 km and Microcells radius generally in the range of 200 m to 300 m. The propagation in these cells is analyzed by diffraction and scattering mechanisms[1]. Indoor propagation losses depends on type of material used for the construction of building, building architecture (i.e. number of windows, doors etc.), floor within the building etc[9,11].

The field measured data was collected during test drive in Gurgaon, India as shown in Figure 1. The relative analysis of various path loss models with drive test measured data is shown in Figure 2. The transmitted power through BTS is 43 dbm, frequency 1800 Mhz (FDD-LTE), transmitted antenna height is 30m and receiving antenna height is 3m.

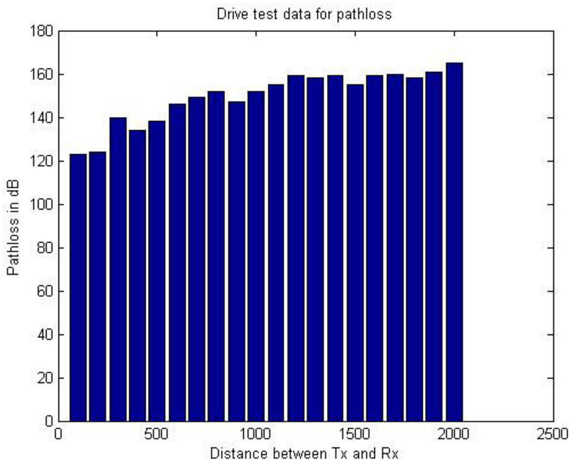

Figure 1. Field measured data during test drive in Gurgaon (India).

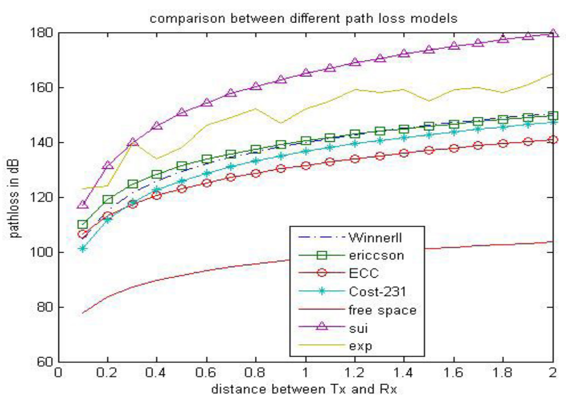

Figure 2. Path loss vs cell radius at antenna height 30m.

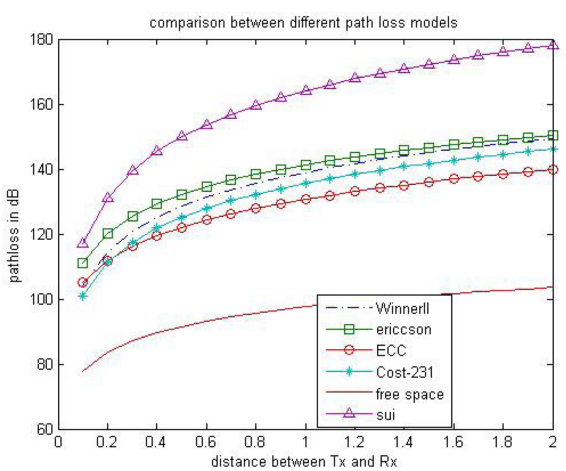

Figure 3. Path loss vs cell radius at transmitter antenna height 35m.

From Figure 2 it is clear that the path loss predicted by SUI model and Ericsson model are near to field measured path loss. But there is significant difference between the predicted value and the measured value. So to design a propagation model in Gurgaon, the difference between predicted value and field measured value has to be considering into account.

The Figure 3 and 4 shows the comparison of path loss predicted by different path loss models with distance between transmitter and receiver i.e. coverage area at 43dbm transmitted power, receiver antenna 3 and frequency of operation of 1800 Mhz at various antenna height.

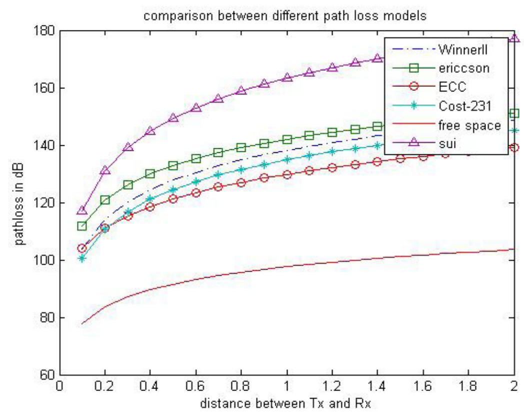

Figure 4. Path loss vs cell radius at transmitter antenna height 40m.

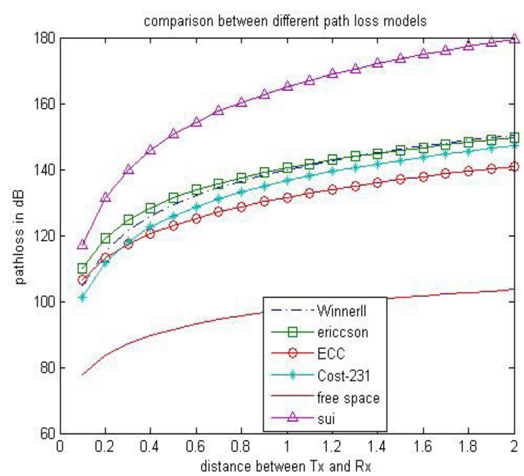

Figure 5. Path loss vs cell radius at transmitter antenna height 30m.

The Figure 5-7 shows the variation of predicted path loss by different propagation path loss models at transmitted power 33dbm, frequency of operation is 1800

MHz and receiver antenna height is 3m. The Figure 5 represents the propagation path loss with cell coverage at transmitter antenna height 30m.

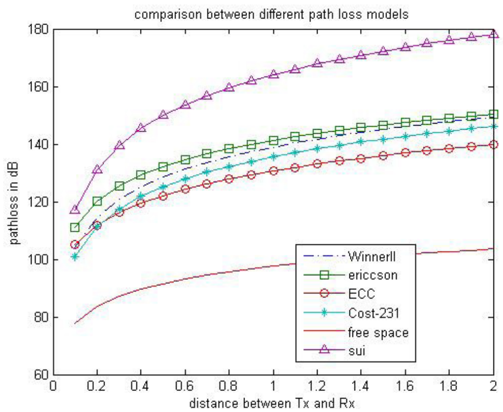

Figure 6. Path loss vs cell radius at transmitter antenna height 35m.

The Figure 6 and 7 shows the comparative analysis of different propagation path loss models at transmitter height 35m and 40m respectively. The Figure 5-7 shows that every propagation path loss model has its own mathematical equation for predicting the path loss. The value of path loss is also different in different transmitter power and different transmitter antenna height.

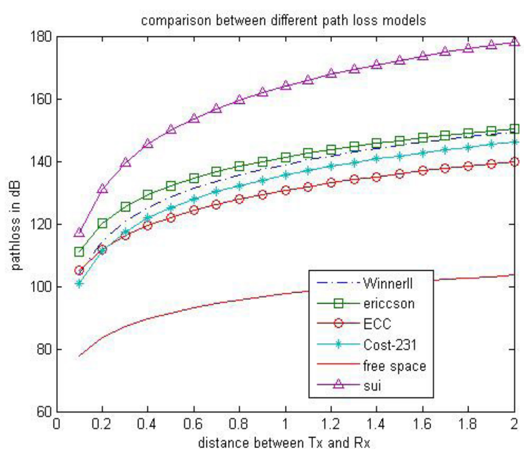

Figure 7. Path loss vs cell radius at transmitter antenna height 40m.

3. Link Budget and its Calculations

Link budget computation is helpful to analyze the total link performance while accounting for the system losses, gain and powers for both transmitter and receiver. The link budget observes the elements that can estimate the signal power achieving at the receiving end. The Figure 8 summarizes input and output of link budget. Link budget is a wireless survey tool which gives an idea about the signal power levels and receiver sensitivity levels needed to render the good link quality. The link budget equation comprises many parameters those are[12,13]:

- Power transmitted by the transmitter.
- Gain of Antenna (both transmitter and receiver).
- Feeder losses of antenna (both transmitter and receiver).
- Path loss.
- Sensitivity of the receiver.
- BTS sensitivity.

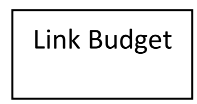

Figure 8. Inputs and outputs of link budget

The formulation of link budget equation is very simple. The link budget equation includes all losses and antenna gains in the total link[14].

$$P_e = P(H_1|H_0)P(H_0) + P(H_0|H_1)P(H_1) \quad (1)$$

We generally take an assumption in the computation of link budget is that the transmitter antenna spreads out the power in all directions equally. This assumption is helpful in theoretical computations, But not for realistic computations. The typical equation for the link budget is:

$$P_{f,i}P(H_0) + P_{m,i}P(H_1) \quad (2)$$

Where: P_{RX}= received power (dBm)

P_{TX} = Output power of the transmitter (dBm)

G_{TX} = Antenna gain of the transmitter (dBi)

G_{RX} = Antenna gain of the receiver (dBi)

L_{TX} = feeder and connector losses (Transmitter) (dB)

L_{FS} = Free space path loss (dB)

L_{FM} = Signal propagation losses (dB)

L_{RX} = Feeder losses (Receiver) (dB)

Balancing the uplink and downlink is the main objective of link budget. BTS and mobile station has different radio frequency architectures so an imbalance is possible at the receiver side. In any communication system it is essential that the required signal levels are to be maintained to assure that the received signal levels are adequate and above the noise level. To maintain the signal levels in a wireless communication system, larger antennas and high transmitter power levels are required and those can be added considerably at the same outgo. So it is required to balance these to minify the outgo of the system. It can be balanced by adjusting the power of BTS. We can decide the cell coverage area by calculating link balance between uplink and downlink.

Two conditions are there to observe the analysis[1].

- The down link power is more than the uplink: It shows that the Range of BTS is more than the Range of MS, and Coverage area is small in actuality than the prediction. This condition is most common one.
- The uplink power is more than the down link: It shows that the Range of BTS less than Range of MS, and we can see no coverage problem in between MS to BTS.

From these two conditions we can conclude that the condition uplink more than down link, is better than uplink less than down link.

3.1 Demonstrative Calculations of MS and BTS Sensitivities

Sensitivity here is the minimal input signal sending from the transmitter which leads to signal to noise at the receiver, more than a threshold value E_b/N_0 related with the performance of the modulator[9]. The Table 1 shows the different standard parameters used for calculations.

(3)

3.2 Link Budget and Cell Coverage (Uplink)

3.2.1 *Transmitter Side*

The Table 2 shows parameters of uplink budget on transmitter end.

Table 1. Different standard parameters and its values.

Parameter	Value
Boltzmann's constant (K)	1.38×10^{-23} J/K^0
Absolute temperature (T)	300 K^0
Equivalent noise bandwidth (B_{eq})	360 KHz
Interference margin	3-8 dB
ME RF Noise figure	6-11dB

$$EIRP= P_{Tx}+ G_{ME} +BL \quad (4)$$

Table 2. Parameters of uplink budget on transmitter end.

Parameters of the Transmitter (Mobile equipment)	Parameter Value
Power of MS (P_{Tx})	24dBm
Antenna gain of the Mobile (G_{ME})	0 dBi
Body Loss (BL)	0
Effective Isotropic Radiated Power (EIRP)	24 dBm
Mobile Station Antenna height (MS) (h_m)	3m

3.2.2 Receiver Side

The Table 3 shows parameters of uplink budget on receiver end.

$$R_s=EIRP-L_p-I_M-C_L-L_c+G_{BTS}- MHAgain \quad (5)$$

Table 3. Parameters of uplink budget on receiver end.

Receiver (BTS)	Parameter value
Noise figure at receiving end	2.0 dB
Thermal noise (T_N)	-118.4dBm
Receiver noise floor (R_{NF})	-116.4dBm
Signal to Noise and Interference Ratio (SINR)	-7dB
Receiver sensitivity (R_S)	-123.4 dBm
cable loss (C_L)	2dB
BTS receiving antenna gain (G_{BTS})	18dBi
Interference margin (I_M)	2dB
Mast Head Amplifier gain (MHA gain)	2 dB
Connector loss (L_C)	2 dB
Antenna height (BS) (h_b)	30m or 35m or40m

Using equation (4)

EIRP=24dB

Using equation (5)

$-123.4 =24-L_p-2-2-2+18-2$

Therefore L_p= 161.4 dB, By using the values of EIRP=24 dB and L_p=161.4 dB in different propagation path loss models such as Cost-231 Model, Ericsson

Model, Winner II Model, ECC-33 Model and SUI Model. The Table 4 shows coverage area of each propagation model with different transmitter antenna height.

Table 4. Coverage area of propagation path model with different transmitter antenna height.

Model	Hb=30m	Hb=35m	Hb=40m
WinnerII	4.084 km	4.42km	4.74km
Cost 231	5.0753km	5.5075km	5.9215km
ECC33	7.5403km	8.1314km	8.6965km
SUI	0.842km	0.88km	0.915km
Ericcson	4.9053km	4.6136km	4.3752km

3.3 Link Budget and Cell Coverage (Downlink)

3.3.1 Transmitter Side

The Table 5 shows parameters of downlink budget on transmitter end.

(6)

Table 5. Shows parameters of downlink budget on transmitter end.

Parameters of the Transmitter (BTS)	Value
BTS output power (P_{TxB})	43dBm
Antenna gain (transmitter) (G_{TXB})	18 dBi
Cable loss (L_{CableB})	1dB
EIRP	59 dBm
Combiner loss (L_c)	1dB

3.3.2 Down link Receiver End

The Table 6 shows parameters of downlink budget on receiver end.

$$R_s=EIRP-L_p-I_M-L_c+G_{BTS}-B_{LM}\ Lp=161.5 \quad (7)$$

Table 6. Parameters of downlink budget on Receiver end.

Receiver (MS or ME)	Parameter value
Noise figure at receiving end	dB
Thermal noise (T_N)	-104.5dBm
Receiver noise floor (R_{NF})	-97.5dBm
Signal to Noise and Interference Ratio (SINR)	-10dB
Mobile station Sensitivity (R_{SM})	-107.5dBm
Body loss (B_{LM})	0.0dB
MS receiving antenna gain (G_{BTS})	0.0dB
Interference margin (I_M)	3dB
Connector loss (L_C)	2dB

By analyzing the whole calculations we found a link difference of 18dbm. This difference can be compensated by increasing the output power of the BTS[1].

4. Conclusions

The analysis of different propagation path loss models has been presented at different transmitting powers and at different transmitting antenna heights. Further this theoretical path loss has been compared with the field collected data in Gurgaon, India for predicting the coverage area at transmitting power 43 dbm. The analysis results are useful for developers at the beginning level of a set up of a wireless system network and to estimate the maximum coverage area. In this paper we calculated link budget to attain balance in between both the links. The uplink power and downlink powers vary because mobile equipment and base station have contrary radio frequency architectures and different level of sensitivities. We can use this link budget to decide the cell coverage.

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