



# Performance Analysis of Path Loss Models at 1.8 GHz in an Indoor/Outdoor Environment to Verify Network Capacity and Coverage

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## Abstract

The effective performance of LTE network is analyzed using signal strength measurements in fading environments. It is one of the primary experimental methodologies for planning and designing a cellular network for given coverage area. In this paper, we present the divergence of path loss between two environments i.e. indoor and outdoor and its effect on coverage and capacity very effectively. The received signal strength and data transfer rate is analyzed at different locations for user's satisfaction. Standard deviation of signal with path loss exponents are calculated based on received signal strength in the operating network areas. It is in the range of 4 to 5.3 in the vicinity of entire urban areas. Path loss using indoors and outdoors model were analyzed effectively and presented. Based on the received signal strength a new path loss model is proposed to meet the requirements of current environment for tuning the path loss model. It is also suggested that, the removal of permanent object within the vicinity of 200 m in front of antenna is considerably a better solution of propagation of signal. The improvement of 27 dBm signal strength around 14 km area is presented with well-installed network if antenna is free from clutter zone. The analyzed parameter may be very effective for 5G communication considering a future network of this era.

**Keywords** Radio propagation · Network planning · Path loss · LTE · Shadow region · Capacity

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## 1 Introduction

LTE is one of the most promising emerging cellular mobile technologies under 802.16p standard. It is a telecommunication technology which enables wireless transmission of voice and data in many ways, ranging from point-to-point links to multipoint links, the so called Broadband Wireless Access (BWA). The signal propagation path is the path from the LTE base station (BS) antenna to the mobile station (MS) antenna depending upon cell coverage. The cell-edge of 2.5 km by single network can deliver 75 Mbps of data rate. It provides more sophisticated services as Internet, TV and high rate data among other services very precisely. Range expansion concept in LTE allows more and more users to be benefited directly. The low power and low cost network follow advance deployment strategy to cover metros, picos, relays and macros to provide adequate coverage and capacity to users. The cell coverage depends upon BS antenna height, tilt, MS antenna height, position of obstructions and other factors [1]. The initial step for planning and designing a mobile cellular network is the prediction of the quality of signal strength received by mobile station, which depends on path loss exponent, shadowing and multipath fading. Study of radio wave propagation in different environments is an essential for designing mobile communication systems. In this paper, the field measurements of received signal strength (RSS) are taken at the frequency of 1.8 GHz in a vehicular and static environment. The received signal levels from the BS were monitored from inside a car moving at a speed of 80–90 km/h and fixed in a lab using spectrum analyzer. Total cell areas consist of different propagation environments like 30% rural and 70% urban areas. The mobile radio propagation particularly in urban areas is quite complicated and it is generally agreed that field measurements are essential for choosing any one of the current prediction models and for developing site specific models. The prediction assumes greater significance in mobile radio because it is direct to the subscriber whereas urban area is directly affected by deep fading elements. [2, 3]. LTE deployment strategy is totally different than GSM and other networks. The deployment plan is user specific but load balancing is another challenge to this network. Key location areas where large customers are involved with value added services through LTE network are not able to provide proper signal strength, hence services decline. Considering all these facts, field measurement technique is adopted to analyze the network on relevant parameters.

## 2 Deployment Strategy and Network Specification

LTE base station deployment plan is a cost effective solution for customer as well as service provider. There is no specific tower but the system is housed in an antenna base and operating without manpower. The scattered deployment of network at every 2–2.5 km distance capturing valuable customer area and providing low cost services to its repute. The resource allocations are decided on a per-scheduling interval basis and it may be based on the number of user served by the macro cell and small cells and their particular data rate requirements [4, 5]. Total 71 towers are installed to capture 16 square kilometer area for better connectivity in urban area and 06 towers for rural area. According to service provider, 10–15% signal are overlapped from same network with minimum interference record. All these towers are internally linked with optical fiber underground cable to support mobility with high accuracy. The System parameters are as follows:

Standard used	IEEE 802.16 p
TX Power	23 dBm
Antenna	3- Sector
Frequency	1.8 GHz
Capacity	≥ 200 active users per 5 MHz cell
Ant type	dish type (01 mtr diameter)
Band width	1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz
Sensitivity	- 103dBm
Ant. Gain	14 dB
Cell radius	2.5 km for each network
Tilt	1.5° down
BS Ant. Height	50 mtr
RX Ant. Height	03 mtr
Peak data Rates	up to 300 Mbps on downlink and 75 Mbps for uplink
Mobility support	up to 300 km/h
Support	2×2 and 4×4 MIMO
Modulation	OFDMA with subcarriers 72, 180, 300, 600, 900 and 1200 with 15 kHz spacing

### 3 RSS Measurements

The signal measurement is a real time quality analyzing procedure of an operating network. The capacity & coverage along with quality of service (QoS) can be determined very effectively. The measurement campaign is planned in vehicular and static mode. In vehicular mode, the variable speed in between 80 and 115 km/h was set to record signal strength in non-busy hour i.e. in mid night around the network in urban and rural areas to check the vehicle speed limitation for connectivity. Secondly, the static measurement is carried out to check the strength of received signal in a particular location where large number of consumers are availing this network services. LTE services are provided by three different operators operating in same vicinity but it was targeted only one network which is offering maximum connectivity. The equipment set up arranged for measurements in lab is shown in Fig. 1.

Broad band antenna having frequency span of 3.2 GHz is connected with low noise amplifier having, NF=2.2 dB, Gain=19 dB, Power 10 mW, Technology of Ga As FET which reduces the noise level and raising the strength of weak signal for required level. 10 dB PAD is provided for observing safety of test equipment's. RF detector (HP) is a square law device which convert sinusoidal signal into square wave for amplitude detection [6]. Signal strength recorder is connected in parallel with spectrum analyzer which record signal during vehicular mode and sometimes in static mode when large variation is observed. The recorded signal were analyzed using Eq. 1 for calculating path loss exponent ( $\alpha$ ) which characterizes the operating environments.

$$P_{RSS} = P_t + K - 10 \alpha \log (d/d_0) + S \quad (1)$$

$P_{RSS}$  = Received signal strength (dBm),  $P_t + K$  = Transmitted Power BS (dB) + Antenna correction factor ( $20 \log_{10}(\lambda / 4\pi d_0)$ ),  $\alpha$  = path loss exponent,  $d$  = Distance in meter (BS-MS),



**Fig. 1** Measurement set up for recording signal strength

$d_0$  = Reference distance in meter (100–200 mtr from Antenna for outdoor and 01 mtr for indoor),  $S$  = Shadow fading (8 dB).

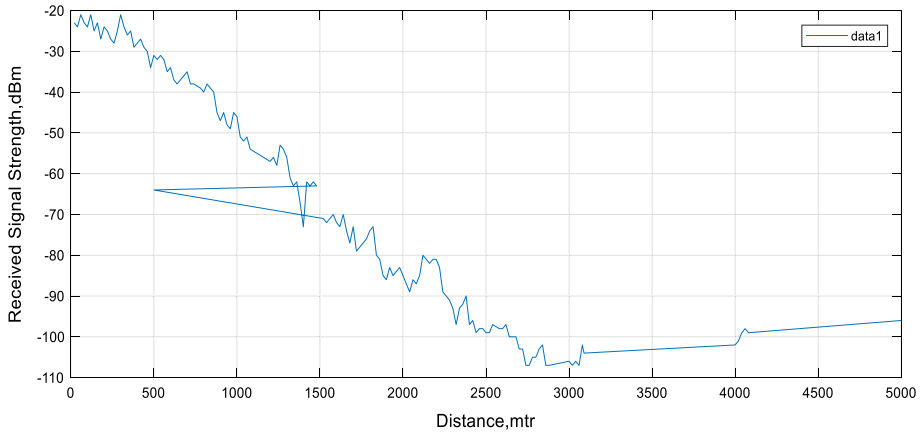
The regression analysis supports the basic idea for a network to predict the coverage for a certain distance depending on receiver threshold. Applying regression fit on the entire set of the measurement data, it was observed that the overall path loss exponents up to 14 km area is ' $\alpha$ ' = 4.6 and standard deviation of signal strength variability ' $\sigma$ ' = 18.23 dB Table 1. The large signal strength deviation is observed in urban area may be due to fading elements. Most of the time operator demanding signal in shadow fading area is also accounted in this Eq. 1 to observe real signal prediction. Reference distance is another factor to suggest real path loss of signal near the tower for installation engineer [7, 8]. Standard deviation is calculated based on received signal strength recorded for different environments using statistical analysis at Mat Lab version 14.6. The signal strength variation up to 5 km represents the thickly populated area where large difficulties are associated with LTE network. It was a task of motivation to analyze the difficulty referred in Fig. 2.

**Propagation in LOS/ NLOS:**

The main objective of calculating path loss is to analyze and model propagation mechanisms below 3 GHz in indoor and outdoor environment. At high frequency, diffraction loss increases rapidly and the multipath propagation model became more important to analyze. It dominate particular at microwave and millimeter wave frequency. The propagation of signal starts in free space but at receiving station difficulty associated with many obstructions. Indoor signal obstructed by multiple walls and other man made materials. Propagation of signal from outdoor to indoor by an operating tower, facing a big challenge to provide suitable received signal strength due to path loss. The path loss

**Table1** Propagation parameters

Environment	Path loss exponent ( $\alpha$ )	Standard deviation $\sigma$ (dB)
Rural (open area)	3.2	4.75
Urban area	5.3	18.23
Total cell area	4.6	12.17



**Fig. 2** Variation of signal in urban area of LTE network

model used for calculation is a combination of outdoor and indoor to summarize and compared with different values [9–11].

1. COST 231

$$\begin{aligned}
 PL(\text{dB}) &= (36.2 + 30.2 * \log_{10}(d)) + (12 * \log_{10}(h_b) * \log_{10}(d)) - (3.2 * \log_{10}(11.75 * h_m)^2) + g(f); \\
 g(f) &= (44.49 * \log(f)) - (4.78 * (\log(f))^2) + s;
 \end{aligned}
 \tag{2}$$

$h_m$  – Height of a mobile station Antenna, 3 mtr,  $h_b$  – Height of a base station Antenna, 50 mtr,  $d$  = Total distance,  $s$  = Shadow fading,  $f$  = Operating frequency

2. LEE Model

$$PL(\text{dB}) = 123.77 + 30.5 * \log(d) + n * \log(f/1800) + s - a_0 \tag{3}$$

$n$  = Path loss exponent = 5.3,  $g_m$  = Gain of mobile antenna = 1dB,  $g_b$  = Gain of base station antenna = 14 dB,  $s - a_0$  = Shadow fading,  $pt = 23$ ,  $a_1 = (h_b/30.48)^2$ ,  $a_2 = (h_m/3)^2$ ,  $a_3 = (pt/10)^2$ ,  $a_4 = (g_b/4)^2$ ,  $a_5 = g_m$

$$a_0 = a_1 + a_2 + a_3 + a_4 + a_5$$

3. One- Slope Model (OSM)

A simplified OSM & LDM is designed to study indoor path loss of a network when distance of antenna is considered as 1 mtr from transmitter. It can also be considered as free space model formula, experimentally (Goldsmith, 2005)

$$PL(\text{dB}) = 10 - 10 * 5.3 * \log_{10}(d) \tag{4}$$

4. Log distance model (LDM)

$$PL(\text{dB}) = P_0 + 5.3 * \log_{10}(d) + 8 \tag{5}$$

5. Proposed Model

$$PL(\text{dB}) = P_0 + \log_{10} \left( \left( \frac{4\pi df}{c} \right)^2 \right) \quad (6)$$

$P_0$  = Reference distance power, dBm.

The parameters used in calculation of proposed path loss is  $P_0$  = Signal at reference distance, dBm,  $d$  = distance, mtr and wave length for LOS communication. In free space propagation normally the curvature of Earth  $\left( \left( \frac{4\pi df}{c} \right)^2 \right)$  is being considered for space environmental conditional. Others parameter which directly affect the propagation in NLOS communication is considered in outdoor path loss model like: LEE & COST – 231 Models. These terms are included in publication [6–9].

The proposed methodology is designed for Line of Site (LOS) Communication and is compared with log distance model. Referring to Fig. 4 in comparative analysis, the response of a standard model used in publication like log distance model for indoor communication is also almost flat. References [5–9] reveals that slight variation in signal is only possible if the range from Base station to Mobile station is of short distance and LOS. Therefore the analysis of path loss is feasible to almost 80 to 90% in synchronization with standard path loss log distance model. Figure 2 shows variation of signal very minute when antenna is in LOS at 3 to 5 km range and 0 to 3 km max variation when it is NLOS [10, 11].

#### 4 Cellular Radio Environments

The environmental effect on LTE network due to fading elements is very critical. Network area consist of high rise buildings, vegetation's, vehicular moment's etc., casting deep shadow on network making a link. In many cases it is observed that, shopping mall and basements are provided with optical links for internet services. The installation of network antenna at 50 mtr height may be losing the ground coverage but satisfactory result is possible at upper floor of a buildings. Phenomena of down tilt support network coverage at some instant on the lower altitude but missing at high altitude [12–14].

Cellular communication systems are designed scientifically to offer desired services under changing system parameters, which depends mainly on propagation characteristics of the radio cell environments [15]. LTE system was specially designed to provide high data rate at low cost [16]. To achieve consistent quality of service across varying propagation environmental conditions, receiver may be tuned to its optimum value or receiver design parameter need to be adapted [12]. Moreover, the field study may also be useful for planning the cellular network for its optimum coverage [17, 18].

#### 5 Un-Planned Installation

The LTE network installation is specifically carried out for maximum revenue collection and the technical parameters for installation are overlooked in many situation. The service providers are not able to compromise in terms of competitive market and location importance. The interference caused by same network in close vicinity is overlooked in many locations. Large numbers of equipment's are fetched in same vicinity to cover maximum consumer in operating areas [19]. Interference using same network in own system became

un-affordable and system lags with downloading speed. It may be enhanced if the installation criterion is followed properly according to the given procedure.

## 6 Practical Network Installation Procedure for Future Network

- a. Theodolite surveying machine- A Theodolite is an instrument which measure both horizontal and vertical angles, as used in triangulation networks, and geo-location work. It is a tool used in the land surveying and engineering industry, but Theodolite have been adapted for other specialized purposes as well. It performs an important role in network installation but failed to utilize this machine in some locations which restrict lesser coverage [20]. This instrument can be utilized to find out strong clutters and permanent echoes falling in front of transmitting antenna. Therefore maximum height of a tower can be decided based on clutters bypass technology. The absorption and reflection of EM waves is totally dependent upon the surface where it propagates. Practically, there should not be any obstruction for EM wave within 200 meters range for better propagation. High tension wire passing near the base station antenna height must be avoided Figs. 3 and 4. [21, 22]
- b. Transceiver system for installation- In this technology, transmitter is set to operate at given operating frequency and placed at a location where network is likely to be installed. In this case many key location areas are to be marked and transmitter can be relocated to transmit signal from different angles. Likewise, different parameters will be recorded for analysis. The suitable parameter based on area specific where minimum attenuation is reflected must be produced for installation [23–25]. It is difficult but technically achievable and may produce long term stability in network operation.

Another procedure is to place transceiver at location and second transceiver is to be placed in vehicle. Try to make a communication link and keep moving in and around the areas. If communication does not fail, that indicates the location is suitable for operation. Same procedure can be adopted for data transfer check also. Likewise, network can be installed in a proper way and may be termed as future network for particular areas [26].

- c. Setting up tilt- Tilting of antenna at particular angles is an alternate procedure for optimizing the network performance [27, 28]. This procedure sets a path to fill the gap where signal is intermittent. Mechanical tilt phenomenon on is very difficult to achieve because

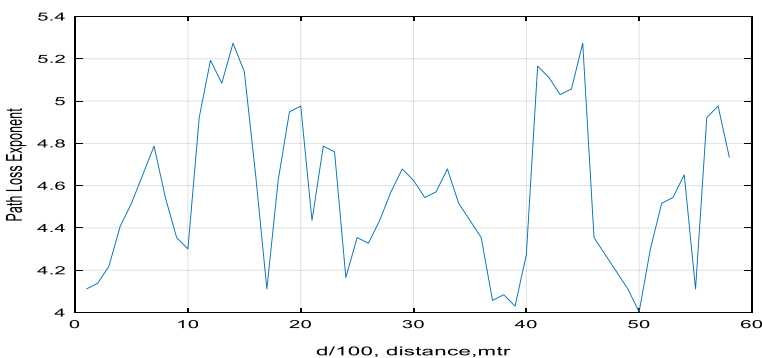
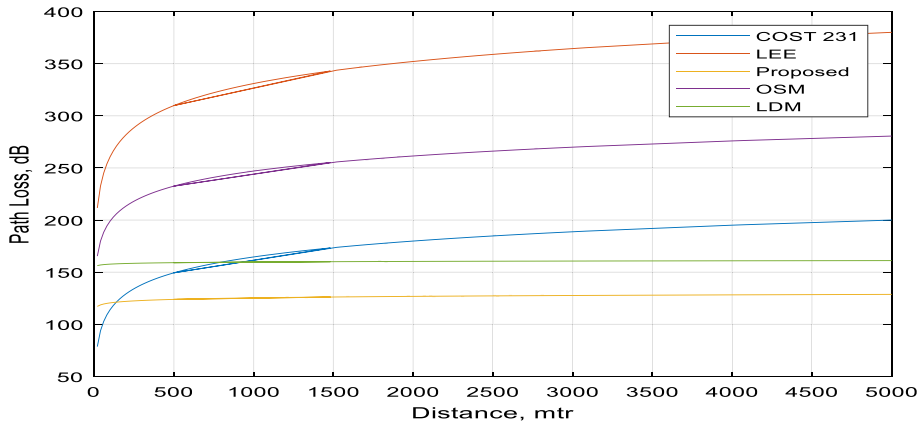


Fig. 3 Variation of path loss exponent, urban areas



**Fig. 4** Path loss model for indoor and outdoor environment

of the height of a tower. Electrical tilt is feasible but accuracy cannot be maintained. Remote electrical tilt is a suitable procedure to cover a particular area under a lobe and set for maximum capacity and coverage with QoS [29].

- d. Power diversity- LTE network transmission is three antenna systems but there is provision to transmit using six antennas also. It may be possible in 5G communication. Provisioning more antennas in transmission will lead to smaller gap in coverage. Now, there is a need that each antenna should transmit a different power according to choice. In a simple way, we can say that, more power should be transmitted in a location where large variation of signal is observed due to traffic load [30] (Fig. 5).

## 7 Result Analysis for Future Networks

Standard procedure during network installation and endurance test provides optimized solution for maximum capacity and coverage [31]. Future network may be advanced LTE or 5G network needs critical study to satisfy the customer needs. Sensor network needs additional care to support uplink/downlink with very high accuracy. Planning procedure started with LTE parameters which exists in current environment and lags with adequate

**Fig. 5** Network Installation in open area for coverage settings





signal strength and data transfer rate. In parallel to this operating network, a full proof installation procedure is adopted to check any discrepancy in installation which hampers the signal strength. The transmitter is tuned to 1800 MHz and set to transmit in same location but at different angles and elevation. This procedure leads to minimum interference of signal by operating networks [32]. Signal strength were recorded for many locations and analyzed critically. The signal strength of existing network and corresponding to data transfer rate were analyzed. The large differences were observed in a network which is operating for covering 16 km of areas. Setting down tilt—2.5° and raising antenna height at 65 m supports very good signal strength in turn data transfer rate corresponding to operating LTE network also raises. 3-D representation shows all the relevant parameters needed for an operating network which is installed in cascade manner. Data transfer rate is taken reference based on received signal strength form operating networks as installation device transceiver can support only audio services [33]. In first part, operating LTE network is analyzed for signal strength and data transfer rate w.r.t distance. Signal strength vs distance is plotted and data transfer rate is kept as a reference to compare with previous signal strength. The operating network shows the lagging performance in busy hours when signal strength reaches at minimum level of - 107 dBm with data transfer rate less than 1 Mb. The presentation on mobile screen display 4G network but performance is less than 3G in terms of practical consideration. Practically installed network shows the leading signal strength and maintaining - 80 dBm around the coverage area w.r.t all the fading environments with data transfer rate of 1-5 Mbps Fig. 6. The rise of 12 to 27 dBm signal strength around the network area promising better solution for future network planning.

$$P_R[P_R(d) > \Upsilon] = \frac{1}{2} = \frac{1}{2} \operatorname{erf} \left( \frac{\Upsilon - \left[ P_t - \left( PL(d_0) + 10n \log \left( \frac{r}{d_0} \right) \right) \right]}{\sigma \sqrt{2}} \right) \tag{7}$$

$P_R[P_R(d) > \Upsilon]$ =Outage Probability.

where  $\Upsilon = P_{\min}$ , is the minimum detectable signal,  $n$  is the path loss exponent,  $\sigma$  is the standard deviation,  $n$  and  $n$  and  $\sigma$  are derived using least square method from received signal strength.  $r$  is the total distance,  $mtr$ .  $d_0$  reference distance,  $mtr$

$$C = Q(a) + \exp((2 - 2ab)/b^2)Q((2 - 2ab)/b) \tag{8}$$

C=Total coverage area

**Fig. 6** Theodolite position for calibration



$$a = (P_{\min} - P_R) / \sigma \text{ and } b = 10 * n \log_{10}(e) / \sigma$$

The performance of any network is justified by its capacity, coverage and quality of services. All these parameters are considered for short distance and long distance communication. When network is operating with master slave operation and all the slave networks is linked using fiber optics, the small variation in signal strength is a practical approach. Its data is presented in 3-D pattern with Fig. 7. The variation of signal strength and data transfer rate is shown with distances. The proposed path loss model in line of sight communication produces flat response at short distance and represent constant data transfer rate and very small variation in signal strength. Therefore, it is suggested that proposed model is environment specific and may be considered for future network [34–37].

## 8 Conclusion

LTE network operating under research area are failed to meet the data transfer rate and minimum signal strength due to interference and shadow fading installation. Service providers are unable to respond the reasons as failure of installation. In challenging environment, the system can respond better if propagation of signal is hurdle free. The analysis of signal propagation reveals that proper installation may enhance the capability of network under the promising range of signal strength – 80 dBm and data transfer rate up to 5 Mbps even in busy hour situation. Standard deviation of signal strength is also maintained within 12 dB. Variation of path loss is significant but comparing indoor and outdoor environment in same scale is another important factor for model tuning in the future networks. The purposed path loss model is providing a flat response at short distance but variable for long distance communication. The compared response with log distance model for indoor environment also remains flat due to Line Of Sight (LOS) communication.

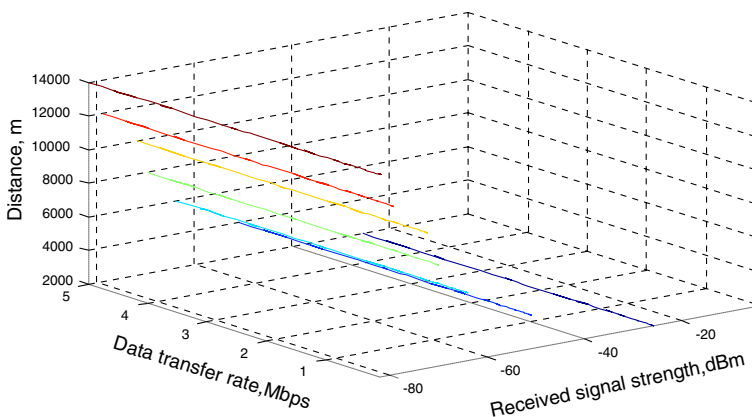


Fig. 7 Performance of interlinked networks

## Declarations

**Conflict of interest** The authors declared that they have no conflict of interest.

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37. Recommendation ITU-R P.2109-0. (2019-08). Prediction of building entry loss.



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