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Performance Evaluation of the Wireless Cellular Network for Path Loss

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***Abstract*—This paper analyses the performance of Wireless cellular network under different environmental conditions. The paper discusses the basic architecture of cellular network and the issues which cause the degradation of quality of signal (QOS) during its propagation in free space. Moreover, the handoff scheme is also described using an on line handoff-initiation-time estimation scheme. Efficient handoff mechanisms are essential for ensuring seamless connectivity and uninterrupted service delivery. Latter the propagation models implemented are: free space path loss, Okumura model, COST 231 Hata model, SUI, ECC-33models and Ericsson model. These models are simulated for standard parameters for Cellular transmission. The results analysed were stated for each model in respective environmental locations. The result implies that the received signal strength depends on the path loss and the parameters of the transmitter and receiver. Quality of call establishment is based on received signal strength.**

Keywords- Wireless communication; cellular network; handoff mechanism; empirical models; path loss.

I. INTRODUCTION

The present decade of the twenty-first century has testified a significant development in the communication networks and their design. In the mean while, a new wireless technology of communication has been evolved from old fixed landline network and has proved to be much efficient in terms of network mobility, connectivity, strength or network power requirements than prior wired networking [1]. Besides the mobility features, wireless networks are also faster, flexible, heterogeneous, secure and economic. Today wireless technology has become the heart of global communication network by supporting billion of users worldwide. The platform of Wireless technology is a free space media so the signal propagation is dependent on environmental factors [2]. Thus being a reliable mode of communication, Wireless communication faces some major environmental issues which adversely affect the network efficiency and signal quality [3]. In order to resolve such environmental issues, different Wireless propagation models have been proposed for various environmental conditions and system requirements. Wireless propagation models define the signal attenuation of as a function of the distance between network terminals. Thus, the deployment of a cellular wireless network is selective in terms of geographical location and user density. That's why the wireless communication networks are evaluated with reference to the backbone propagation model [4].

II. FUNDAMENTALS OF CELLULAR NETWORK

The explosive popularity of wireless network is due to proliferation of cellular radio devices and cellular network. The major credit for this wide acceptance of modern wireless network is its cellular topology with virtue of which it can accommodate large users in limited bandwidth [5]. In cellular topology the coverage area is divided into many non overlapping cells and a set of channels are assigned to each of these cells. This same set of channels is later used in some another cell at certain distance away from primary cell as shown in Figure 1. This concept of using same frequency channels again and again in a specific arrangement across the whole coverage region is termed as Frequency reuse [6]. In this way the cellular topology increases the capacity of a wireless system, allowing more users to communicate simultaneously. This concept of cellular topology, where each cell is controlled by a base station, to be used to improve the communication capacity of a wireless system, was first proposed in 1947 by Bell Laboratories in the US, with a detailed proposal for a "High-Capacity Mobile Telephone System" incorporating the cellular concept submitted by Bell Laboratories to the FCC in 1971 [5]. The most commonly considered model of cellular structures hexagon (as shown in Figure 1) because of the fact that the hexagonal shape is geometrically uniform in considering the radiation pattern of base station antennas in all directions. It also assists in readily calculating the SIR. The size of clusters commonly used in reuse purpose contains three or seven cells and later is repeated in particular fashion as shown in Figure 1.

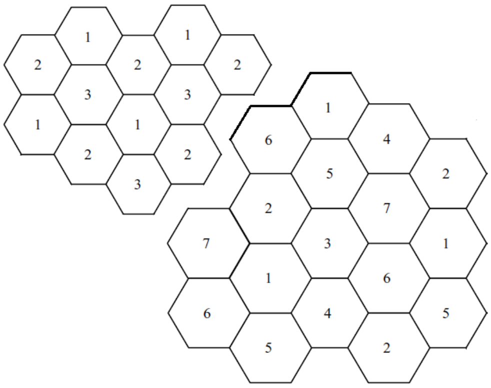

Figure 1. A Hexagonal cell pattern in Cellular network.

III. CELLULAR NETWORK ISSUES

The wireless cellular communication network provides the comfort of mobility to the user by multiple connection points in a network and also across multiple networks as the user moves from one location to another. The facility of roaming within a same type of technology i.e intra-network or among different technologies i.e. inter-network, requires the switching of connection point from home network to new host. This process which supports switching mechanism from one wireless point to another is termed as handoff [6]. This handoff is preformed to avoid degradation of signal level due to increasing distance between mobile terminal and server point wireless connection and thus there is a need to switch the connection to another point of connection located in current region. This implies that the handoff is extremely important exercise in cellular mobile networks. The implementation of this inter- or intra-network handoff is a typical process which involves selection of certain parameters with the aid of decision making algorithms. These pre-handoff parameters are assumed in a manner to maximize the quality of service for the user and minimize the use of system resources. A number of algorithms are being employed or investigated to optimize the decision making process for handoff. Traditional algorithms employ simple intuitive rules to compare the received signal strength from different points of connection and then decide on when to make the handoff [7]. But these simple decision mechanisms result in the several consecutive handoffs thereby degrading the service provided by the network. Consequently, more complex algorithms are needed to decide on the optimal time for handoff. However, on the comparative performance evaluation of different handoff algorithms for selecting the optimum handoff decision algorithm are seen to be dependent on the type of network. Traditional cellular networks are primarily focused on voice applications and consequently minimizing the number of handoffs and ping-pong effects. The rate adaptive and heterogeneous data networks are focused on optimizing the delivered average throughput to the user. However, this average throughput is affected by different factors in a heterogeneous and in a homogeneous multi-rate network [7]. This analysed from the performance of different models by calculating path loss. The path loss defines the reduction in power density of an electromagnetic wave as it propagates in free space. This purpose is fetched by calculating the received signal strength of base station with noise and without noise for an area as shown in Figure 2 [6].

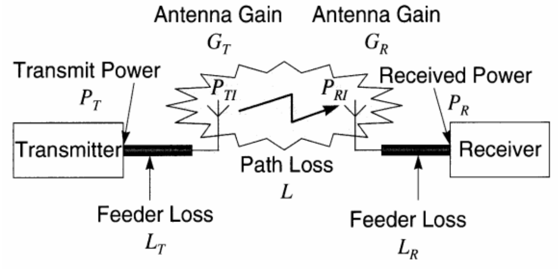

Figure 2. Concept of Path Loss.

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Handoff is initiated either by crossing a cell boundary or by deterioration in quality of the signal in the current channel. A call in progress could be forced to abort during handoff if sufficient resources cannot be allocated in the new wireless cell. A properly designed handoff algorithm is essential in reducing the switching load of the system while maintaining the quality of service (QoS) [6]. In general, the first step of handoff is initiation phase where Received Signal Strength (RSS) is measured according to the radio propagation based methods, and a new candidate base station (BS) is chosen if necessary. In mobile communication, the received signal strength is a measurement of power present in a received radio signal. Signal strength between base station and mobile must be greater than threshold value to maintain signal quality at receiver (Figure 3). The second step is the execution phase, a new radio channel will be assigned, and the call will be handed over to another BS (Figure 3) [6].

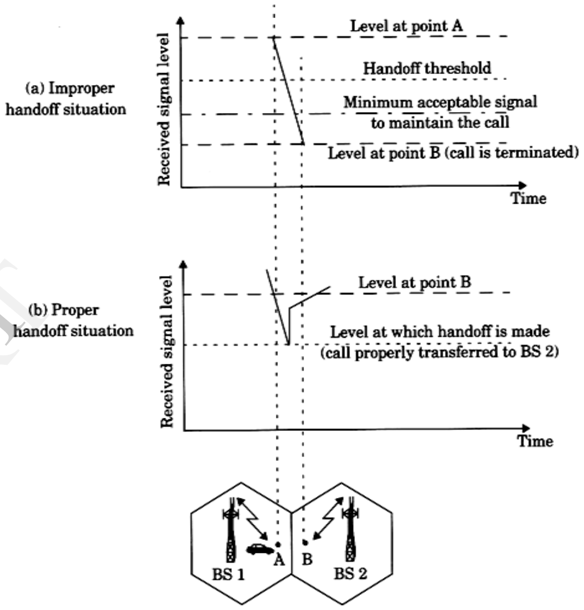


Figure 3. Diagrammatic presentation of handoff process.

Figure 3 shows the handoff threshold that is a minimum acceptable signal to maintain the call. So to provide ubiquitous network access for mobile communication devices, service providers have to build networks that deploy several points of connection. In cellular voice telephony and mobile data networks, such points of attachment are referred to as base stations (BSs) or access points (APs) [7]. The key issues for handoff failures are: lack of channel availability on selected BS, lack of resources, time delay to set up the handoff at initiation, failure of target link during the execution or high Path loss during the transmission etc. Therefore, the received signal strength must be important factor for handoff. Handoff is used if RSS of an active base station decreases below threshold level. The RSS can be calculated with empirical models as [6]:

$$P_r = P_t + G_t + G_r - PL - A \qquad (1)$$

where, P_r: received signal strength (dB), P_t: transmitted power (dB), G_t: transmitted antenna gain (dB), G_r is received antenna gain (dB), PL is total path loss (dB), and A is connector and cable loss (dB). Thus, received signal strength is used to determine the point of handoff.

IV. WORK METHOLOGY

The major steps involved in this research work are summarized in figure 4 below. The first step is to find some suitable method for calculating the path loss to investigate the point of handoff. Latter the performance of cellular network will be analysed for various path loss models across diverse environmental conditions.

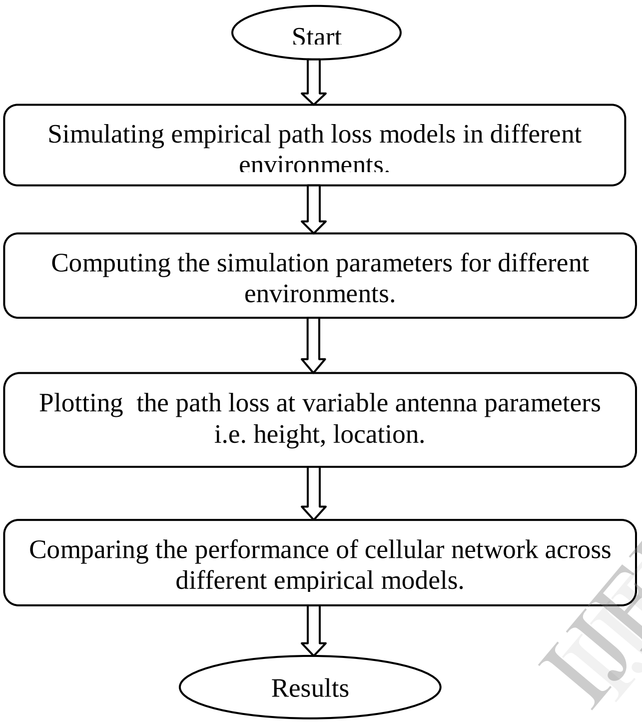


Figure 4. Layout of the work methology.

V. IMPLEMENTATION OF EMPIRICAL MODELS

The system applications of a wireless network are dependent on implementation of Empirical models that describe the attenuation of the transmitted signal as a function of the distance between network terminals [8]. Empirical models are based on statistical characterization of the received signal extensive measurements conducted with respect to several different parameters. Some empirical models combine the analytical formulation of physical phenomena with statistical fitting of variables by adjustment using experimental measurements. Hence, the choice of empirical model plays an important role in the performance of a cellular network. In this study standard Empirical models are implemented in different environments like suburban area scattered with trees, houses and urban areas with large building and houses or village with close houses and tall trees. These empirical models are described below:

A. Free Space Path Loss Model (FS)

Free space model defines the path loss in the form of lost signal strength during propagation from transmitter to receiver. as describe in the following equation:

$$PL_{FS} = G_t - G_r + 32.44 + 20\ log(d) + 20log(f) \qquad (2)$$

where, Gt and Gr are transmitted and received antenna gains in dB; d is T-R separation (Km) and f is frequency (MHz) [9].

B. Okumura Model

The Okumura model is a widely accepted empirical model used to measure the radio signal strength and predict path loss in urban, suburban and rural area up to 3 GHz. Median path loss model can be expressed as [10]:

$$PL_{OM} = L_f + A_{mn}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \qquad (3)$$

where, PL_{OM} : Median path loss (dB), L_f : Free space path loss [dB], $A_{mn}(f,d)$: Median attenuation relative to free space (dB), $G(h_{te})$: Base station antenna height gain factor (dB), $G(h_{re})$: Mobile station antenna height gain factor (dB), G_{AREA}: Gain due to the type of environment (dB), f: Frequency (MHz), h_{te}: Transmitter antenna height (m), h_{re}: Receiver antenna height (m) and d: Distance between transmitter and receiver (km).

C. COST 231 Hata Model

The Hata model is used for the frequency range of 150 to 1500 MHz to predict the median path loss for the distance up to 20 km, and transmitter antenna height is considered 30 m to 200 m and receiver antenna height is 1 m to 10 m [11]. The basic path loss equation for this COST-231 Hata Model is given by [12]:

$$PL_{COST} = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + c_m \qquad (4)$$

where d: Distance between transmitter and receiver antenna [km], f: Frequency [MHz], h_b: Transmitter antenna height [m]. The parameter c_m has different values for different environments like 0 dB for suburban and 3 dB for urban areas.

D. Stanford University Interim (SUI) Model

The SUI model came from the extension of Hata model with frequency larger than 1900 MHz. The correction parameters are allowed to extend this model up to 3.5 GHz band. In the USA, this model is defined for the Multipoint Microwave Distribution System (MMDS) for the frequency band from 2.5 GHz to 2.7 GHz [13]. The base station antenna height of SUI model can be used from 10 m to 80 m. Receiver antenna height is from 2 m to 10 m. The cell radius is from 0.1 km to 8 km [14]. The SUI model describes three types of terrain: A, B and C. Terrain A can be used for hilly areas with moderate or very dense vegetation while terrain B is characterized for the hilly terrains with rare vegetation, or flat terrains with moderate or heavy tree densities and terrain C is suitable for flat terrains or rural with light vegetation. The basic path loss expression of the SUI model is presented as:

$$PL_{SUI} = A + 10y\log_{10}(d/d_0) + X_f + X_h + s \quad \text{for } d > d_0 \qquad (5)$$

where, the parameters are d: Distance between BS and receiving antenna [m], X_f: Correction for frequency above 2 GHz [MHz], X_h: Correction for receiving antenna height [m], S: Correction for shadowing [dB] and Y: Path loss exponent. The random variables are taken through a statistical procedure as the path loss exponent Y and the weak fading standard deviation s is defined. The log normally distributed factor S, for shadow fading because of trees or other clutter on a propagations path and is between 8.2 dB and 10.6 dB [13]. The constants a, b, and c depend upon the types of terrain, given in Table I.

TABLE I. PARAMETER VALUES OF DIFFERENT TERRAIN FOR SUI MODEL

Model Parameter	Terrain A	Terrain B	Terrain C
A	4.6	4.0	3.6
$B\ (m^{-1})$	0.0075	0.0065	0.005
$C(m)$	12.6	17.1	20

E. Hata-Okumura extended model or ECC-33 Model

Hata-Okumura model is based on the Okumura model[11]. This model is a well-established model for the Ultra High Frequency (UHF) band up to 3.5 GHz [15]. The path loss is given by [13]:

$$PL_{HO} = A_{fs} + A_{bm} - G_b - G_r \qquad (6)$$

where A_{fs}: Free space attenuation [dB], A_{bm}: Basic median path loss [dB], G_b: Transmitter antenna height gain factor and G_r: Receiver antenna height gain factor. These factors can be separately described and given as:

$$A_{fs} = 9.24 + 20\log_{10}(d) + 20\log_{10}(f) \qquad (7)$$

$$A_{bm}=20.41+9.83\log_{10}(d)+7.894\log_{10}(f)+9.56[\log_{10}(f)]^2 \qquad (8)$$

$$G_b = \log_{10}(h_b/2000)\{13.958 + 5.8[\log_{10}(d)]^2\} \qquad (9)$$

For medium cities, the G_r will be expressed as:

$$G_r = [42.57 + 13.7\log_{10}(f)][\log_{10}(h_r) - 0.585] \qquad (10)$$

For large city: $$G_r = 0.759(h_r) - 1.862 \qquad (11)$$

where, d: distance between transmitter and receiver antenna (km), f: Frequency (GHz), h_b: Transmitter antenna height [m] and h_r: Receiver antenna height (m).

F. Ericsson Model

This model compensates variations in signal parameters because of environment. Path loss for this model is given by:

$$PL_{EM} = a_0 + a_1.\log_{10}(d) + a_2.\log_{10}(h_b) + a_3.\log_{10}(h_b).\log_{10}(d) - 3.2(\log_{1o}(11.7h_r)^2) + g(f) \qquad (12)$$

and $$g(f) = 44.49\log10(f) - 4.78(\log10(f))^2 \qquad (13)$$

where parameters f: Frequency [MHz], h_b: Transmission antenna height [m], h_r: Receiver antenna height [m] and values for a_0, a_1, a_2 *and* a_3 are given in Table II[14].

TABLE II. PARAMETERS FOR ERICSSON MODEL.

Environment	a_0	a_1	a_2	a_3
Urban	36.2	30.2	12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.6	12.0	0.1

VI. SIMULATION PARAMETERS

For simulation model, the operating frequency is 3.5GHz; distance between transmitter antenna and receiver antenna is 5 km, transmitter antenna height is 30 m in urban and suburban area and 20 m in rural area. The 3 different antenna heights for receiver i.e. 3 m, 6 m and 10 m is considered. An average building height of 15 m and building to building distance of 50 m and street width of 25 m is taken. Most of the models provide two different conditions i.e. LOS and NLOS. This study is concentrated on NLOS condition except in rural area, where LOS condition for COST 231 W-I model is considered. The following Table III presents the parameters applied in simulation.

TABLE III. SIMULATION PARAMETERS

Parameters	**Values**
Base station transmitter power	43 dBm
Mobile transmitter power	30 dBm
Transmitter antenna height	30 m in urban and suburban and 20 m in rural area
Receiver antenna height	6 m
Operating frequency	3.5 GHz
Distance between Tx-Rx	5 km
Building to building distance	50 m
Average building height	15 m
Street width	25 m
Street orientation angle	300 in urban and 400 in suburban
Correction for shadowing	8.2 dB in suburban and 10.6 dB in urban area

VII. RESULTS

This research study tests the Cellular Empirical models in different environments i.e. urban, suburban and rural areas.

A. Path loss in urban area

Here receiver antenna heights i.e. 3m, 6m, 10m; transmitter antenna height is 30 m are taken in urban area at distance of 250m to 5km. The results are shown in Figures 5, 6 and 7.

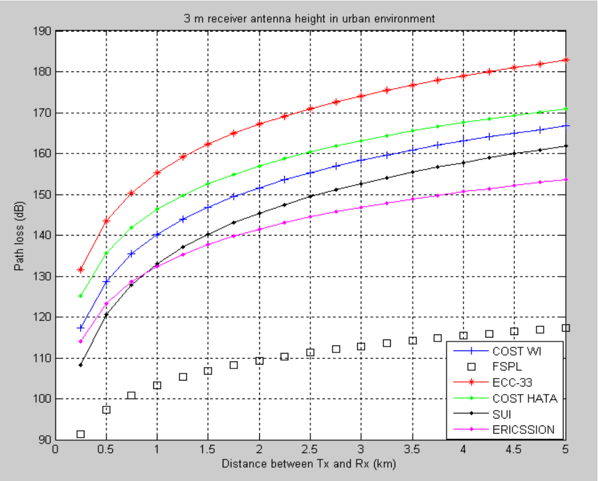


Figure 5. Path loss in urban environment at 3 m receiver antenna height.

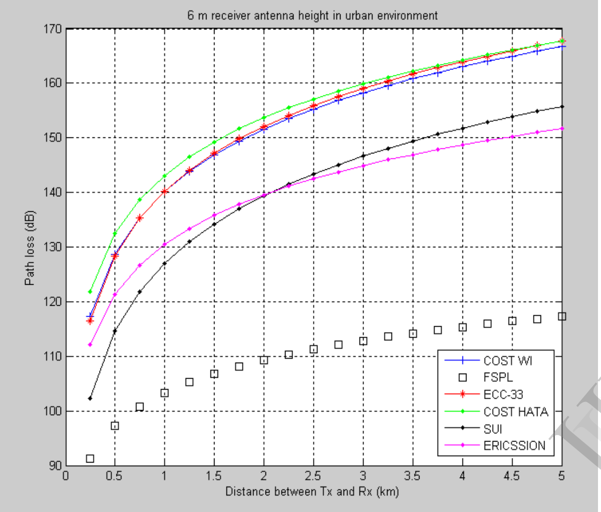


Figure 6. Path loss in urban environment at 6 m receiver antenna height.

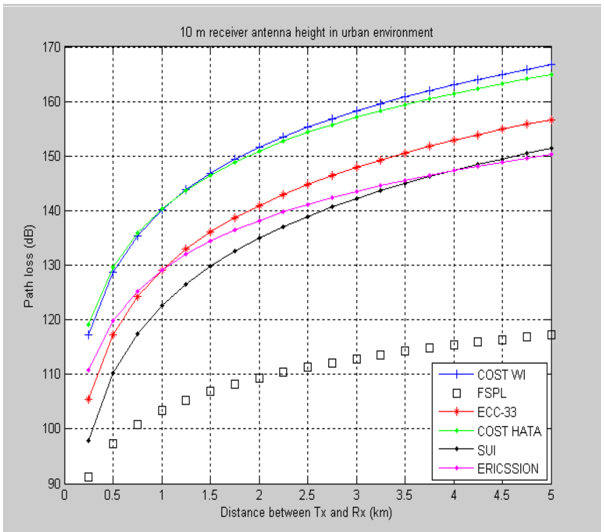


Figure 7. Path loss in urban environment at 10 m receiver antenna height.

Table IV summarized the path loss data at 2 km Tx-Rx distance in urban environment. Path loss seems to vary with the changes of receiver antenna height.

TABLE IV. PATH LOSS AT 2KM DISTANCE IN URBAN ENVIRONMENT

Empirical Models	**Tx antenna ht. (m)**	**Tx power (dBm)**	**Path loss (dB)**		
			Rx antenna ht . = 3m	*Rx antenna ht.= 6 m*	*Rx antenna ht. =10 m*
FSP L	30	43	110	110	110
ECC-33	30	43	167	152	141
COST H	30	43	157	154	150
Ericsson	30	43	142	140	138
SUI	30	43	154	148	144
COST WI	30	43	159	156	151

B. Path loss in suburban area

The antenna heights are same as earlier. The results for suburban area are shown in Figure 8, 9 and 10.

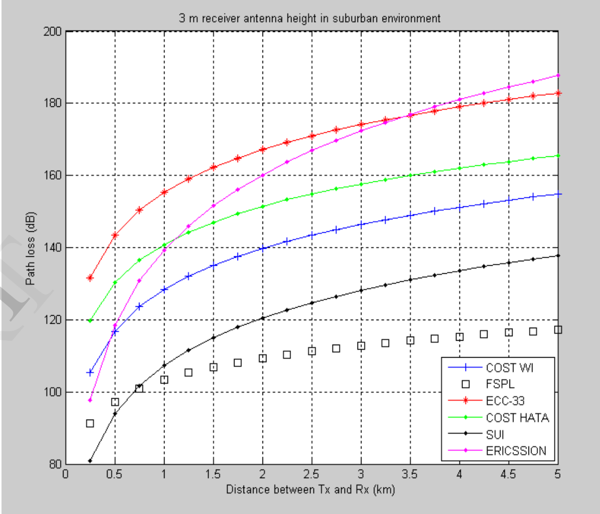


Figure 8. Path loss in suburban environment at 3 m receiver antenna ht.

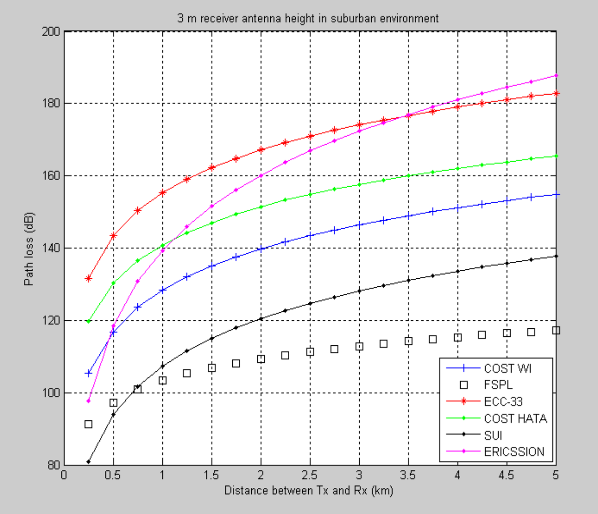


Figure 9. Path loss in suburban environment at 6 m receiver antenna ht.

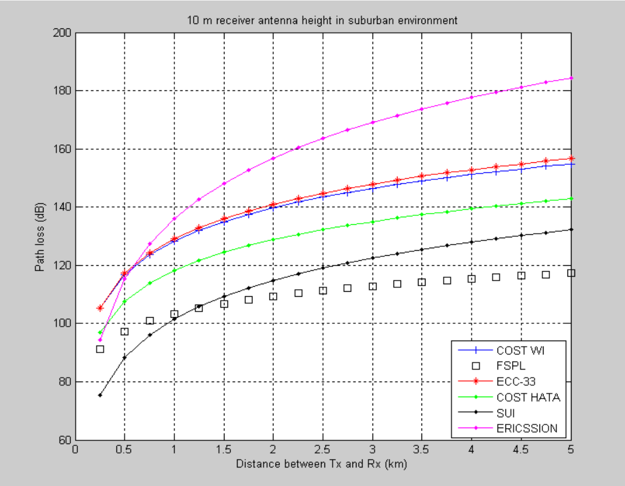


Figure 10. Path loss in suburban environment at 10 m receiver antenna ht.

Table V summarized the path loss data at 2 km Tx-Rx distance in suburban environment. Path loss is varied according to the changes of receiver antenna height.

Empirical Models	**Tx antenna ht. (m)**	**Tx power (dBm)**	**Path loss (dB)**		
			Rx antenna ht . = 3m	*Rx antenna ht.= 6 m*	*Rx antenna ht. =10 m*
FSP L	30	43	110	110	110
ECC-33	30	43	167	152	141
COST H	30	43	152	142	130
Ericsson	30	43	160	157	156
SUI	30	43	121	118	115
COST WI	30	43	147	145	140

TABLE V. PATH LOSS AT 2KM DISTANCE IN SUB-URBAN ENVIRONMENT

C. *Path loss in suburban area*

The Rx antenna hts. are same as earlier while for Tx antenna ht. is considered as 20 m. The results for different models in rural area are shown in Figure 11, 12 and 13. Table VI summarized the path loss data at 2 km Tx-Rx distance in rural environment.

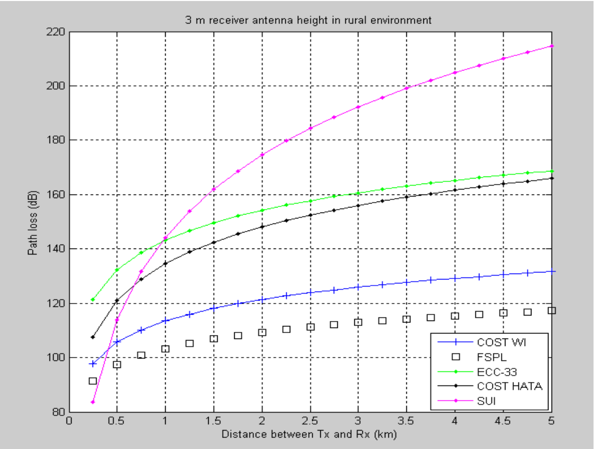
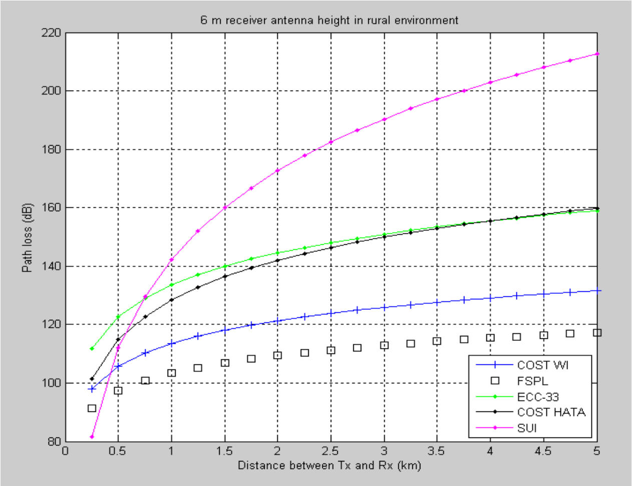


Figure 11. Path loss in rural environment at 3 m receiver antenna height



.Figure 12. Path loss in rural environment at 6 m receiver antenna height.

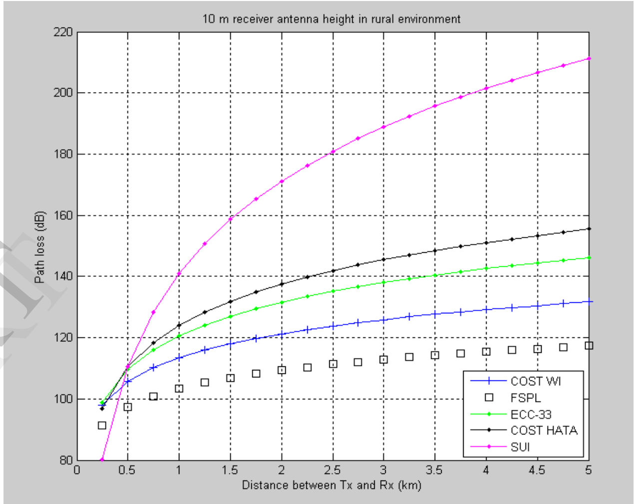


Figure 13. Path loss in rural environment at 10 m receiver antenna height.

TABLE VI. PATH LOSS AT 2KM DISTANCE IN RURAL ENVIRONMENT

Empirical Models	**Tx antenna ht. (m)**	**Tx power (dBm)**	**Path loss (dB)**		
			Rx antenna ht . = 3m	*Rx antenna ht.= 6 m*	*Rx antenna ht. =10 m*
FSP L	30	43	110	110	110
ECC-33	30	43	167	152	141
COST H	30	43	152	142	130
Ericsson	30	43	160	157	156
SUI	30	43	121	118	115
COST WI	30	43	147	145	140

VIII. CONCLUSION

From the performance analysis made in this paper, it is found that Ericsson model showed the lowest prediction (142 dB to 138 dB) in urban environment. It also showed the lowest fluctuations compare to other models when we changed the receiver antenna heights. In that case, the ECC-33 model showed the heights path loss (167 dB) and also showed huge fluctuations due to change of receiver antenna height. In this model, path loss decreases when the receiver antenna height increases. Increasing the receiver antenna heights provides more probability to find the better quality signal from the transmitter. COST 231 W-I model showed the biggest path loss at 10 m receiver antenna height as shown in figure 14. The SUI model predicts the lowest path loss (121 dB to 115 dB) in this terrain with little bit flections at changes of receiver antenna heights. Ericsson model showed the heights path loss (157 dB and 156 dB) prediction especially at 6 m and 10 m receiver antenna height. The COST-Hata model showed the moderate result with remarkable fluctuations of path loss with-respect-to antenna heights changes. The ECC-33 model showed the same path loss as like as urban environment because of same parameters are used in the simulation as shown in figure 15. COST 231 Hata model showed the lowest path loss (129 dB) prediction especially in 10 m receiver antenna height and also showed significant fluctuations due to change the receiver antenna heights. COST 231 W-I model showed the flat results in all changes of receiver antenna heights. There are no specific parameters for rural area. In our simulation, we considered LOS equation for this environment (the reason is we can expect line of sight signal if the area is flat enough with less vegetations). Ericsson model showed the heights path loss (173 dB to 168 dB) which is remarkable, may be the reason is the value of parameters *a0* and *a1* are extracted by the LS methods as shown in figure 16.

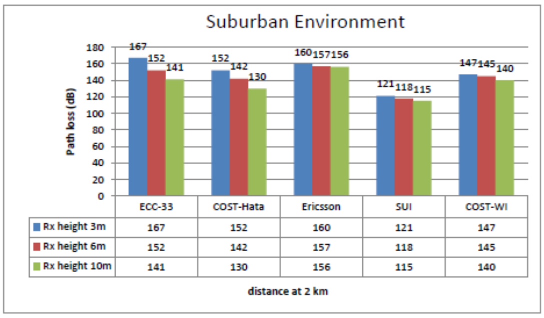


Figure 14: Performance Analysis of results in urban environment.

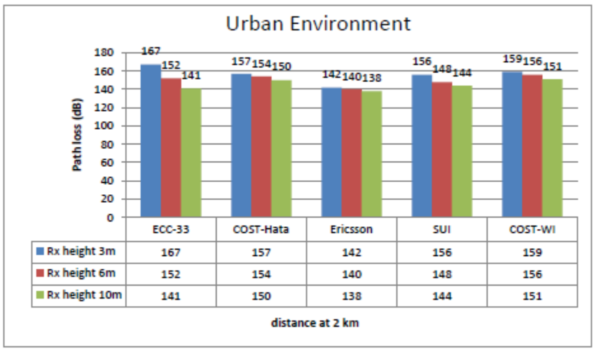


Figure 15: Performance Analysis of results in sub-urban environment.

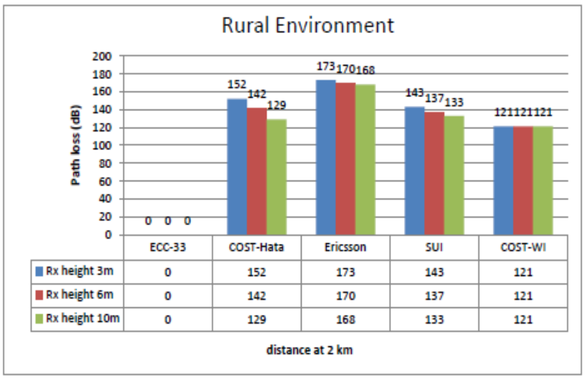


Figure 16: Performance Analysis of results in rural environment.

From the results, it is observed that there is no individual sole model that can be recommended for all environments. So, one needs to predefine required relation between transmission power and signal interference while choosing an Empirical model for deploying Cellular network in a geographical location.

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