Study and Comparison of Radio Wave Propagation Model for Different Antenna

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***Abstract*— *The performance of different mobile network technologies can be evaluated using system level simulations. The radio wave propagation model also known as path loss model plays a very significant role in planning of any wireless communication systems. In this work, COST 231 radio propagation model is studied for the Long Term Evolution (LTE) networks using different antenna systems. A comparison is made between different antenna systems for finding the path-losses. Different COST 231 radio propagation model based terrains has been studied and compared, such as, urban, suburban area under micro and macro level.*

Keywords — *Long term evolution, Berger antenna, pathloss, radio wave propagation model, TS 36.942, COST 231.*

I. INTRODUCTION

Long Term Evolution (LTE) is the latest step in moving forward from the cellular 3rd Generation (3G) to 4th Generation (4G) services. LTE is often described as a 4G service but it is not fully compatible to 4G standards [1]. An improved version of LTE known as LTE advance is a 4G compatible technology. Both LTE & LTE advance uses the same frequency band. LTE is based on standards developed by the 3rd Generation Partnership Project (3GPP) [2]. LTE offers significant improvements over previous technologies such as Universal Mobile Telecommunications System (UMTS) and High-Speed Packet Access (HSPA) by introducing a novel physical layer and reforming the core network [3-5]. The main reasons for these changes in the Radio Access Network (RAN) system design are the need to provide higher spectral efficiency, lower delay, and more multi-user flexibility than the currently deployed networks [2]. In the development and standardization of LTE, as well as the implementation process of equipment manufacturers, simulations are necessary to test and optimize algorithms and procedures [6]. This has to be performed on both, the physical layer (link-level) and in the network (system-level) context.

The selection of a suitable radio propagation model for LTE is of great importance. A radio propagation model describes the behavior of the signal while it is transmitted from the transmitter towards the receiver [7]. It gives a relation between the distance of transmitter & receiver and the path loss. From this relation, one can get an idea about the allowed path loss and the maximum cell range [8]. Path loss depends on the condition of environment (urban, rural, dense urban, suburban, open, forest, sea etc), operating frequency, atmospheric conditions, indoor/outdoor & the distance between the transmitter & receiver [9-11].

In this paper, a comparison is made between different radio propagation models in different terrains to find out the model having least path loss in a particular terrain and which has the highest..

II. RADIO PROPAGATION MODELS

A. *SUI Model*

Stanford University Interim (SUI) model is developed for IEEE 802.16 by Stanford University [12] [13]. It is used for frequencies above 1900 MHz. In this propagation model, three different types of terrains or areas are considered. These are called as terrain A, B and C. Terrain A represents an area with highest path loss, it can be a very dense populated region while terrain B represents an area with moderate path loss, a suburban environment. Terrain C has the least path loss which describes a rural or flat area.

The path loss in SUI model can be described as

$$PL = A + 10\gamma \log\left(\frac{d}{d_0}\right) + X_f + X_h + S$$

where PL represents Path Loss in dBs, d is the distance between the transmitter and receiver, d_0 is the reference distance (Here its value is 100), X_f is the frequency correction factor, X_h is the correction factor for BS height, S is shadowing & γ is the path loss component and it is described as

$$\gamma - u - bh_b + \frac{c}{h_b}$$

where h_b is the height of the base station and a, b and c represent the terrain for which the values are selected as shown in Table I.

TABLE 1
DIFFERENT TERRAINS & THEIR PARAMETERS

Parameters	Terrain A	Terrain B	Terrain C
a	4.6	4	3.6
b(1/m)	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

The free space path loss (A) is given by

$$A = 20\log\left(\frac{4\pi d_0}{\lambda}\right)$$

where d_0 is the distance between T_x and R_x and λ is the wavelength. The correction factor for frequency & base station height are as follows:

$$X_f = 6\log\left(\frac{f}{2000}\right)$$

$$X_h = -10.8\log\left(\frac{h_r}{2000}\right)$$

where f is the frequency in MHz, and h_r is the height of the receiver antenna. This expression is used for terrain type A and B. For terrain C, the expression shown below is used.

$$X_h = -20\log\left(\frac{h_r}{2000}\right)$$

$$S = 0.65(\log f)^2 - 1.3\log(f) + \alpha$$

Here, α = 5.2 dB for rural and suburban environments (Terrain A & B) and 6.6 dB for urban environment (Terrain C).

B. Okumura Model

Okumura model [14] [15] is one of the most commonly used models. Almost all the propagation models are enhanced form of Okumura model. It can be used for frequencies up to 3000 MHz. The distance between transmitter and receiver can be around 100 km while the receiver height can be 3 m to 10 m. The path loss in Okumura model can be calculated as

$$PL(db) = L_f + A_{m,n}(f,d) - G(h_t) - G(h_r) - G_{AREA}$$

Here L_f is the free space path loss and it is calculated by the following expression:

$$L_f = -20\log\left(\frac{\lambda}{4\pi d_0}\right)$$

where G(h_t) and G(h_r) are the BS antenna gain factor and receiver gain factors respectively. Their formulas are as follows:

$$G(h_t) = 20\log\left(\frac{h_b}{200}\right)$$

$$G(h_r) = 10\log\left(\frac{h_r}{3}\right)$$

where h_b and h_r are the heights of base station and receiver receptively. $A_{m,n}(f,d)$ is called as median attenuation factor. Different curves for median attenuation factor are used depending on the frequency and the distance between the transmitter and receiver. The area gain G_{AREA} depends on the area being used.

C. Cost-231Hata Propagation Model

COST-231 Hata model is also known as COST Hata model. It is the extension of Hata model [16] and it can be used for the frequencies up to 2000 MHz. The expression for median path loss, PLU, in urban areas is given by

$$PL(dB) = 46.3 + 33.9\log(f) - 13.02(h_b) - a(h_r) + \left[44.9 - 6.55\log(h_b)\right].\log(d) + c$$

Here, f represents the frequency in MHz, d denotes the distance between the transmitter & receiver, h_b & h_r the correction factors for base station height and receiver height respectively. The parameter c is zero for suburban & rural environments while it has a value of 3 for urban area. The function a(h_r) for urban area is defined as:

$$a(h_r) = 3.2\left(\log(11.75h_r)\right)^2 - 4.97$$

and for rural & suburban areas its is as follows:

$$a(h_r) = 1.1\log(f) - 0.7h_r - (1.58f - 0.8)$$

D. COST-231 Walfisch-Ikegami Model

COST-231 Walfisch-Ikegami model is an extension of COST Hata model [17]. It can be used for frequencies above 2000 MHz. When there is Line of Site (LOS) between the transmitter & receiver the path loss is given by the following formula:

$$PL = 42.64 + 26\log(d) + 20\log(f)$$

While in Non-Line of Sight (NLOS) conditions, path loss is given as:

$$PL = L_0 + L_{RTS} + L_{MSD}$$

where L_0 is the attenuation in free-space and is described as:

$$L_0 = 32.45 + 20\log(d) + 20\log(f)$$

L_{RTS} represents diffraction from rooftop to street, and is defined as:

$$L_{RTS} = -16.9 - 10\log(w) + 10\log(f) + 20\log(h_b - h_r) + L_{ORI}$$

Here LORI is a function of the orientation of the antenna relative to the street a (in degrees) and is defined as:

$$L_{ORI} = \begin{cases} -10 + 0.354a & for\ 0<a<35 \\ 2.5 + 0.075(a-35) & for\ 35 < a < 55 \\ 4 - 0.114(a-55) & for\ 55 < a < 90 \end{cases}$$

LMSD represents diffraction loss due to multiple obstacles and is specified as:

$$L_{MSD} = L_{BSH} + k_A + k_D\log(d) + k_F\log(f) - 9\log(S_b)$$

where

$$L_{BSH} = \begin{cases} -18\log(1 + h_t - h_b) & for\ h_t > h_b \\ 54 + 0.8(h_t - h_b)2d & for\ h_t \le h_b \\ & and\ d < 0.5\ km \end{cases}$$

$$k_A = \begin{cases} 54 \quad for\ h_t > h_b \\ 54 + 0.8(h_t - h_b)2d \quad for\ h_t \le h_b \\ \quad and\ d < 0.5\ km \end{cases}$$

$$k_D = \begin{cases} 18 + 15\left(\frac{h_t - h_b}{h_b}\right) \quad for\ h_t > h_b \\ 18 \quad for\ h_t \le h_b\ and\ d < 0.5\ km \end{cases}$$

$$k_F = -4 + k\left(\frac{f}{924}\right)$$

Here, k = 0.7 for suburban centers and 1.5 for metropolitan centres.

E. Ericsson 9999 Model

This model is implemented by Ericsson as an extension of the Hata model [18]. Hata model is used for frequencies up to 1900 MHz. In this model, we can adjust the parameters according to the given scenario. The path loss as evaluated by this model is described as:

$$PL = a_0 + a_1 \log(d) + a_2 \log(h_b) + a_3 \log(h_b)\log(d)$$
$$-3.2(\log(11.75))^2 + g(f)$$

where

$$g(f) = 44.49\log(f) - 4.78((\log(f))^2$$

The values of a_0, a_1, a_2 and a_3 are constant but they can be changed according to the scenario (environment). The defaults values given by the Ericsson model are a_0 = 36.2, a_1 = 30.2, a_2 = 12.0 and a_3 = 0.1. The parameter f represents the frequency.

III. Methodology

In our simulation, operating frequency of 2.6 GHz has been selected and the minimum coupling losses selected is 70 dB. COST 231 models are selected for this work and the pathlosses were estimated using different antennas. Three different antennas were analyzed for this system design evolutions. The antennas selected are: omnidirectional antenna, Berger antenna and TS 36.942. The results were evaluated for 1000 m distance. Similarly four different multipath fading has been selected. These are; COST 231 urban micro, COST 231 urban macro, COST 231 suburban macro, and freespace. Some other input parameters selected is shown in Table 2.

The current LTE multi-antenna design supports up to four antenna ports with corresponding cell-specific reference signals in the downlink, in combination with codebook-based pre-coding. However for this work, only 2 antenna ports were used with transmission bandwidth of 1 MHz. the antenna model can be used in conjunction with hexagonal deployment models to represent realistic well planned deployment conditions in system simulations and performance evaluations.

TABLE II
SIMULATION PARAMETERS

Traffic Model	
User Distribution	Uniform
Network Model	
Distance attenuation	L = 35.3+37.6·log(d), d = distance in meters
Shadow fading	Log-normal, 8 dB standard deviation
Multipath fading SCM	Urban micro, urban macro, suburban macro
Cell layout	Hexagonal grid, 3 sector sites
Cell radius	334m (1000m intersite distance)
System Model	
Spectrum allocation	5MHz bandwidth at 2GHz
Max antenna gain	15dBi
Modulation and coding	QPSK & 16QAM, 3GPP turbo codes
UE antennas	2 per UE with half-wavelength spacing
Network antennas	2 per cell with 10-wavelength spacing

IV. Results and Discussions

The impact of the different antenna models on system performance of 3GPP LTE has been evaluated. Three different antennas that have been considered are Omnidirectional antenna, Berger antenna and TS 36.942. Fig. 1 shows the respective path losses while studying the COST231 urban micro model, COST231 urban macro model, COST231 suburban macro model, and for free-space system while considering omnidirectional antenna design.

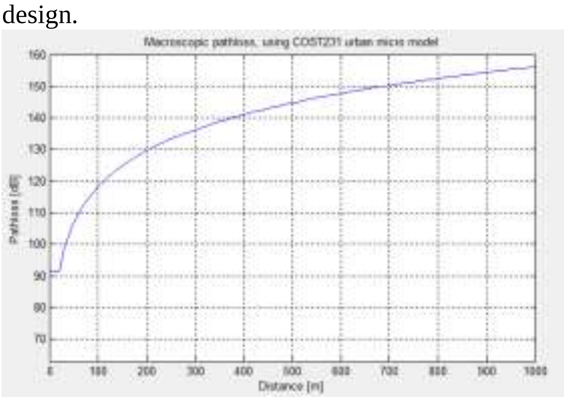

Fig. 1(a) Graph showing pathloss with respect to distance for COST231 urban micro model using omnidirectional antenna.

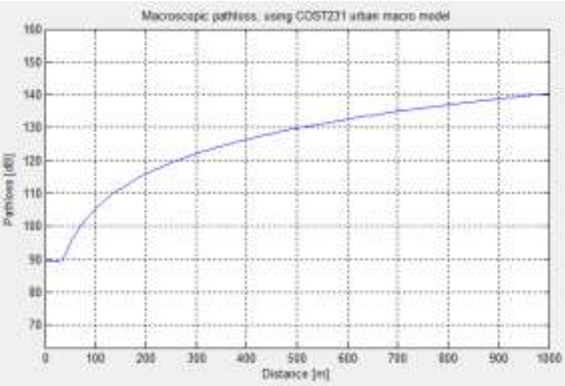

Fig. 1(b) Graph showing pathloss with respect to distance for COST231 urban macro model using omnidirectional antenna.

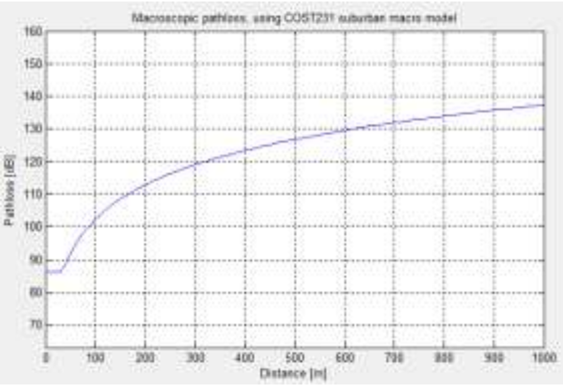

Fig. 1(c) Graph showing pathloss with respect to distance for COST231 suburban macro model using omnidirectional antenna.

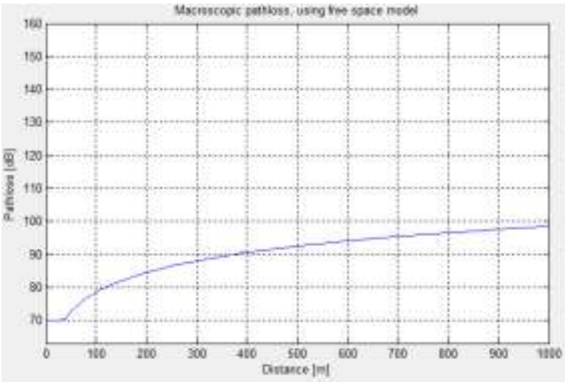

Fig. 1(d) Graph showing pathloss with respect to distance for free space model using omnidirectional antenna.

Fig. 2 shows the path losses for COST231 urban micro model, COST231 urban macro model, COST231 suburban macro model, and free-space system while studying Berger antenna.

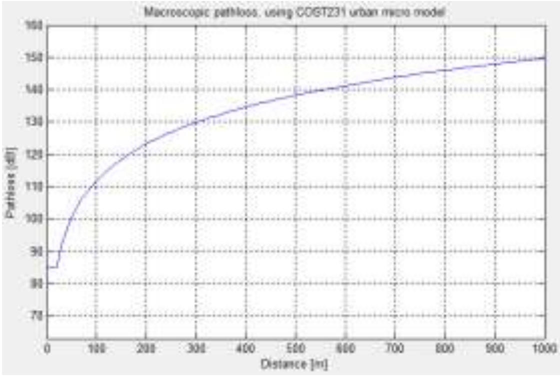

Fig. 2(a) Graph showing pathloss with respect to distance for COST231 urban micro model using Berger antenna.

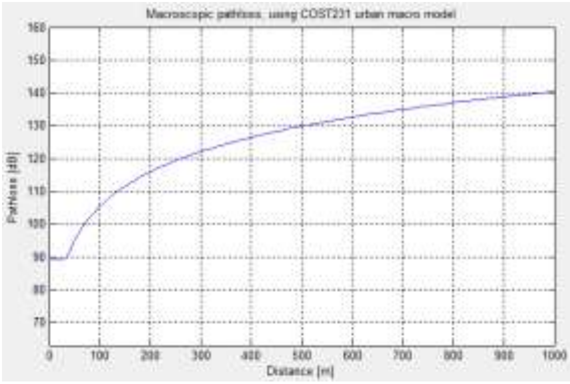

Fig. 2(b) Graph showing pathloss with respect to distance for COST231 urban macro model using Berger antenna.

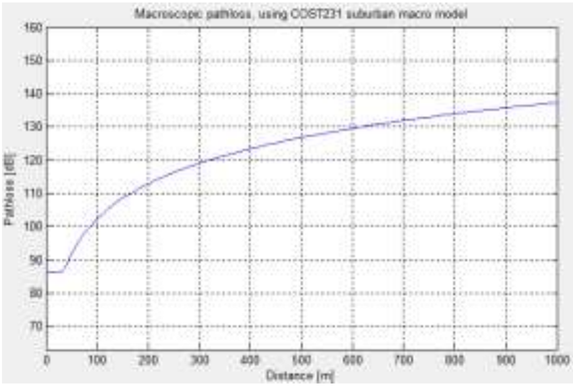

Fig. 2(c) Graph showing pathloss with respect to distance for COST231 suburban macro model using Berger antenna.

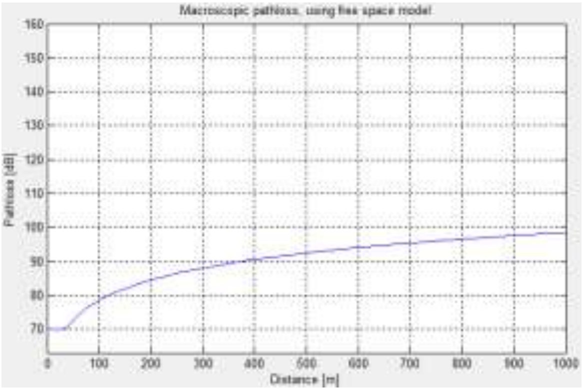

Fig. 2(d) Graph showing pathloss with respect to distance for free space model using Berger antenna.

Similarly, Fig. 3 shows the path losses for COST231 urban micro model, COST231 urban macro model, COST231 suburban macro model, and free-space system while studying TS 36.942 antenna.

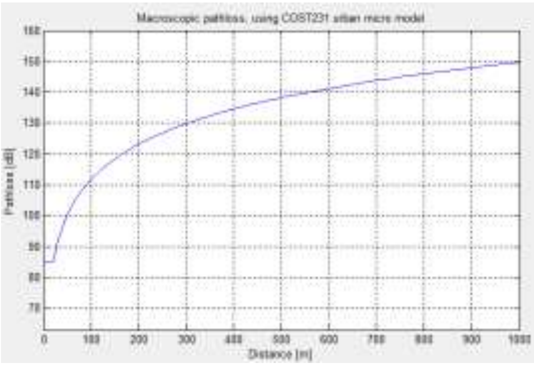

Fig. 3(a) Graph showing pathloss with respect to distance for COST231 urban micro model using TS 36.942 antenna.

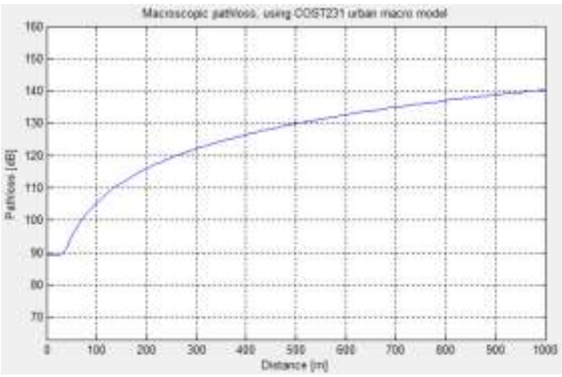

Fig. 3(b) Graph showing pathloss with respect to distance for COST231 urban macro model using TS 36.942 antenna.

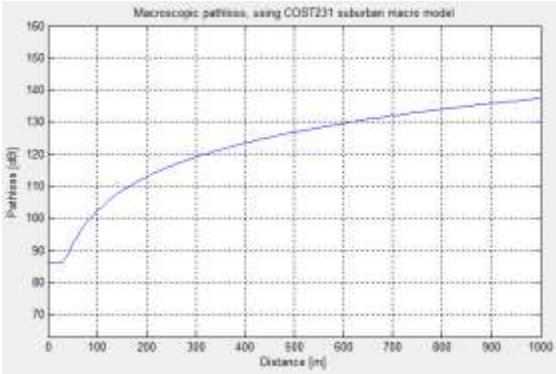

Fig. 3(c) Graph showing pathloss with respect to distance for COST231 suburban macro model using TS 36.942 antenna.

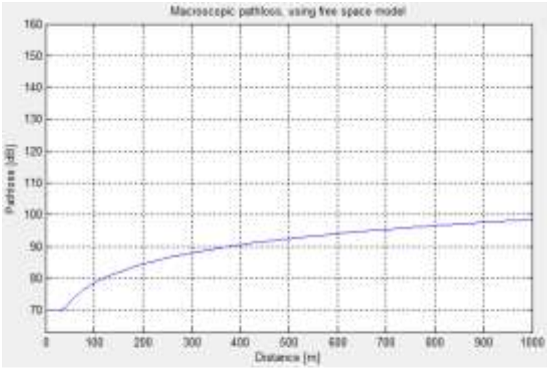

Fig. 3(d) Graph showing pathloss with respect to distance for free space model using TS 36.942 antenna.

From the graphs, it is clear that each antenna provides different path losses for different model. The gain for each antenna is set to 15 dB. The path losses are compared with the free space model also. However, the study showed better results for TS 36.942 antenna for all model systems.

V. Conclusions

In this work, advanced LTE model has been studied for evaluation of path-losses while considering different antennas. The results are also compared with the standard free space model. From the results, it can be concluded that the path losses are higher for omnidirectional antenna while it is comparable while using Berger and TS 36.942 antennas. However, the TS 36.942 antenna showed better results than the Berger antenna for 1000 m transmission distance.

References

[1] E. Dahlman, S. Parkvall, J. Skold, and P. Beming, 3G Evolution: HSDPA and LTE for Mobile Broadband, Academic Press, Jul. 2007.

[2] 3GPP TR 36.912 V2.0.0, "3rd Generation Partnership Project; Technical Specification Group Radio Access

Network; Feasibility study for Further Advancements for E-UTRA (LTE-Advanced) (Release 9)", Aug 2009.
[3] LTE an Introduction, White paper, Ericsson AB, 2009.
[4] J.G Andrews, "Interference Cancellation for Cellular Systems: A Contemporary Overview," IEEE Wireless Communications Magazine, April 2005.
[5] W. Mohr, "The WINNER (Wireless World Initiative New Radio) Project - Development of a Radio Interface for Systems beyond 3G." in Proc. of IEEE Personal Indoor and Mobile Radio Conference 2005 (PIMRC05), Berlin, Germany, Sep 2005.
[6] 3GPP TR36.912, "Feasibility Study for Further Advancements for E-UTRA (LTE-Advanced)," v9.3.0, June 2010.
[7] F. Boccardi and H. Huang, "Limited Downlink Network Coordination in Cellular Networks," in Proceedings of the 18th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2007), September 2007, Athens, Greece.
[8] Borko Furht, Syed A. Ahson, "Long Term Evolution: 3GPP LTE Radio and Cellular Technology", Crc Press, 2009, ISBN 978-1-4200-7210-5.
[9] T.S. Rappaport, "Wireless Communications Principles and Practice", Prentice-Hall, India, 2006.
[10] M. A. Alim, M. M. Rahman, M. M. Hossain, A. Al-Nahid, "Analysis of Large-Scale Propagation Models for Mobile Communications in Urban Area", International Journal of Computer Science and Information Security (IJCSIS), Vol. 7, No. 1, 2010.
[11] S. Jing, D.N.C Tse, J.B Soriaga, J. Hou, J.E Smee and R. Padovani, "Downlink Macro-Diversity in Cellular Networks," in Proceedings of the IEEE International Symposium on Information Theory (ISIT 2007), June 2007, Nice, France.
[12] Josip Milanovic, Rimac-Drlje S, Bejuk K, "Comparison of propagation model accuracy for WiMAX on 3.5GHz," 14th IEEE International conference on electronic circuits and systems, Morocco, pp. 111-114. 2007.
[13] V.S. Abhayawardhana, I.J. Wassel, D. Crosby, M.P. Sellers, M.G. Brown, "Comparison of empirical propagation path loss models for fixed wireless access systems," 61th IEEE Technology Conference, Stockholm, pp. 73-77, 2005.
[14] Okumura, Y. a kol, "Field Strength and its Variability in VHF and UHF Land-Mobile Radio Service", Rev. Elec. Comm. Lab, No.9-10, pp. 825 - 873, 1968.
[15] B. Ramakrishnan, R. S. Rajesh and R. S. Shaji "An Efficient Vehicular Communication Outside the City Environments", International Journal of Next Generation Networks (IJNGN), volume 2, December 2010.
[16] COST Action 231, "Digital mobile radio towards future generation systems, final report", tech. rep., European Communities, EUR 18957, 1999.
[17] Amarasinghe K.C., Peiris K.G.A.B., Thelisinghe L.A.D.M.D., Warnakulasuriya G.M., and Samarasinghe A.T.L.K "", Fourth International Conference on Industrial and Information Systems, ICIIS 2009, 28 - 31 December 2009, Sri Lanka
[18] N. Shabbir, H. Kasihf, "Radio Resource Management in WiMAX," MS thesis, Blekinge Institute of Technology, Karlskrona, Sweden, 2009.