Analysis of WiMAX Radio Measurements and Comparison with Some Models over Dense Urban Western India at 2.3 GHz

Chhaya Dalela, M. V. S. N. Prasad, P. K. Dalela, and Rajeev Saraf

Abstract—**The characteristics of the path loss in the 2.3 GHz band were measured in dense urban environment. Experiments at this frequency using WiMAX transmissions were conducted in dense urban western India. Coverage predictions using various models and their comparison with measured data were carried out. Path loss exponents, mean errors and standard deviations of all the prediction methods were deduced and suitable models for the path loss prediction identified.**

Index Terms— **Path loss, path loss exponent, propagation model, WiMAX**

I. Introduction

BROADBAND Wireless Access (BWA) systems such as WiMAX (Worldwide Interoperability for Microwave Access), based on the standard IEEE 802.16, gained popularity as a reliable last-mile access as well as a backhaul technology. In order to provide guaranteed Quality of Services (QoS), the technology-specific Radio Network Planning (RNP) is required. In a specific frequency band, the coverage, the capacity, the QoS and the interference are the key aspects of RNP. For specific equipments and frequency band, the propagation model is the key parameter for RNP. Signal propagation models are extensively used in such network planning, particularly for conducting feasibility studies and performing initial system deployment. Recent developments in the telecom sector of India showed the Government's initiative for the coverage of rural and urban areas with broadband systems and spurred, in India, lots of activity in the WiMAX systems based on IEEE 802.16 standard. In the WiMAX technology, spectrum managers in India are allocating either 2.3 or 3.5 GHz band depending on availability. The first major study on the comparison of the different propagation models with measurements taken at Cambridge, as far as the authors were aware, was reported by Abhayawardhana *et al.* [1], at 3.5 GHz. The various countries have conducted radio channel measurements in the 2.3/3.5 GHz band in rural and urban areas [2]–[5]. In India, where the environment is different from those in western countries, for instance, in terms of non-uniform building heights, geometry, construction material, road width, etc., no such major WiMAX measurements, however, were reported. In order to fill up this gap, experiments were conducted at seven sites in mostly dense urban region of Mumbai, India, in collaboration with Lepton Software Pvt. Ltd. [6]. The measured signal levels have been converted into path loss using antenna gain, feeder loss, etc. [7], and these path loss values have been compared with those predicted by several models, namely, COST-231 Hata [8], ECC [9], SUI [10] and ITU-R (NLOS) [11] at 2.3 GHz. Path loss exponents from the measured data have been deduced; suitable models have been identified after comparing their prediction Mean Errors (ME) and Standard Deviations (SD).

In Section II, experimental details have been provided. In Section III, we have analyzed the measured path loss data and compared them with the existing path loss models. Conclusions are presented in Section IV.

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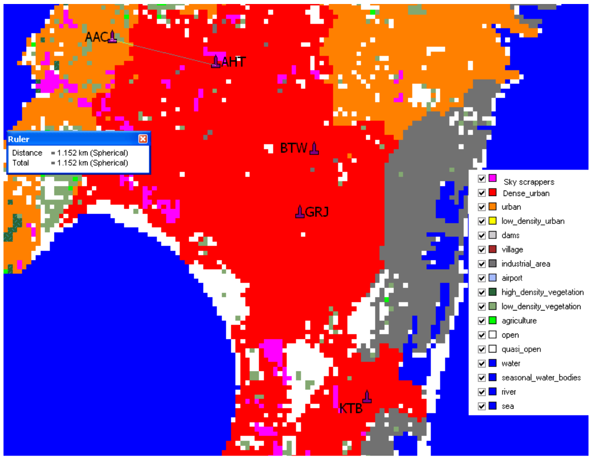
II. EXPERIMENTAL DETAILS

A. Equipment Description

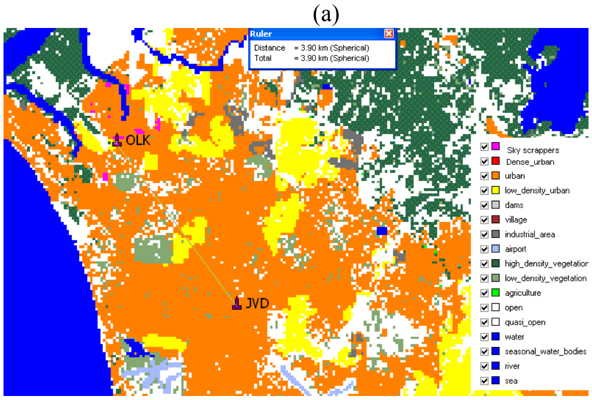
The details of the base stations are shown in Table I. The transmitting antenna used in the present study was the omni-directional antenna TW2.3/OMNI/8dBi [12]. The transmitter and receiver used for experiment were Tortoise dual-band transmitter and Coyote dual-band receiver [13] at 2.3 GHz. The averaging of 512 samples per second in temporal and spatial zone (40-Lambda) has been done. The omni-directional receiver antenna with 2dBi gain was used for the present study. The calculated average received power has been used to estimate the path loss [7] (maximum value 171 dB) corresponding to each measurement.

B. Environmental Details

The experimental sites: AAC, AHT, BTW, KTB, GRJ, JVD and OLK are situated in dense urban area of Mumbai, India except AAC, JVD and OLK which are located in urban area (Figs. 1 (a) and (b)). The clutter environments of these sites are shown in different colors in the legend of Figs. 1 (a) and (b). Since AAC (Fig. 1(a)) and OLK (Fig. 1(b)) are surrounded by skyscraper buildings, so they represent a typical dense urban environment. AHT (Fig. 1(a)) shows the presence of skyscraper at north, east and west sides while the remaining other areas are dense urban in nature. BTW (Fig. 1(a)) is fully surrounded by dense urban environment; industrial environment is present on eastern side beyond 0.7 km of BTW base station site, while urban environment is present towards north side beyond 0.3 km of BTW base station site.



(a)



(b)

Fig. 1 Clutter environment for experimental sites (a) AAC, AHT, KTB, BTW, and GRJ and (b) OLK and JVD.

GRJ (Fig. 1(a)) is fully dense urban in nature, which has industrial environment on eastern side after 0.9 km from GRJ base station site. KTB (Fig. 1(a)) lies in dense urban with coastal area at 0.5 km towards east from KTB base station site; while skyscrapers are located in western side of KTB at 0.2 km, industrial area covers southern side.

III. ANALYSIS OF MEASURED DATA

A. Path loss Analysis

The path loss values for experimental sites have been predicted by the COST-231 Hata model (using the assumptions for 'urban' [1]), ECC (applying 'large city' option for AAC, AHT and OLK sites and using 'medium city' option for BTW, GRJ, KTB, and JVD sites [9]). Study has also been made with the SUI (using terrain type 'B' [10] with the value of shadow fading term equal to 9 dB, as mentioned in Table I) and the ITU-R (NLOS) [11] methods. Figs. 2–4 show the comparison of observed path loss values with predicted path loss values for AAC, KTB and GRJ base stations along with the Least Square (LS) regression line plotted on the measured data. The observed path losses varied from 100 to 120dB, up to 500 m, and beyond that from 110 to 170 dB. In the case of other base stations, too, similar trend was observed. With all the base stations, ECC and COST-231 Hata methods show a good agreement with measured data and followed the regression line very closely (Figs. 2-4, Table II), the former giving a better agreement than the latter (Figs. 3-4). Further, SUI and ITU-R (NLOS) methods have been found to have overestimated the loss (Figs. 2-4). The path loss exponents, the ME and the SD of all the prediction methods have been calculated and shown in Table II. LS represents the regression analysis of measured results. Here, the error is taken as the difference between measured and predicted loss. The SD of these errors has been calculated. While evaluating the path loss exponent for the ECC model, the standard practice of taking path loss gradient at 2 km has been followed [14], and for COST-231 Hata, the path loss exponent n is taken as [14]:

$$n_{\text{COST-231Hata}} = \left(44.9 - 6.55\log_{10}(h_b)\right)/10 \quad (1)$$

where h_b is base station antenna height in meters. LS regression analysis was taken as the basis for comparison of the models. The path loss at a distance d is given by [15]

$$PL(d) = PL(d_o) + 10n\log_{10}\left(\frac{d}{d_o}\right) + s \qquad d > d_o \quad (2)$$

where n denotes the path loss exponent, d is the distance between the transmitter and the receiver stations, d_o is the reference distance point at 100 m, s is the shadow fading term and $PL(d_o)$ is the path loss at range d_o. Path loss exponents from the observed data have been deduced by least square method so that the difference between the measured and estimated path loss value can be minimized in a mean square error sense with the help of (2). By definition, the regression analysis has zero ME. An examination of Table II shows that the path loss exponents deduced from the COST-231 Hata (1) and the ECC models agree very well with the measured values (LS regression), except for AHT base station where the measured values are of higher order as 6.0. Path loss exponents found by the SUI and ITU-R (NLOS) methods are around 4 and 3.8 respectively for all the base stations. SD of LS regression varied from 5.9 to 8.6 which matched well with those predicted by the ECC and the COST-231 Hata methods (Figs. 2-4). This variation could be attributed to the degree of urbanization and geometrical configuration of buildings, which varies from base station to base station. Abhayawardana *et al.* [1] observed that the ECC model showed the closest agreement with the measurement results in comparison with COST-231 Hata and SUI model. In Comparison to the experimental data, the COST-231 Hata model underestimates the path loss, while the ECC model shows the best performance (Figs. 2-4). Thus, for KTB base station, the ECC model over-predicts the measured data by 2.3 dB whereas the COST-231 Hata model has mean prediction error of 9.9 dB with the same value of SD of prediction error i.e. 5.9 dB. Further, the SUI and the ITU-R (NLOS) models over-predict the path loss (Figs. 2-4). Mardeni and Siva Priya [16], optimized COST-231 Hata model at 2.3 GHz in suburban and open urban environments in Malaysia. They observed that COST-231 Hata method had close agreement in terms of path loss exponent and SD error analysis. In our analysis, the COST-231 Hata model showed better agreement with LS regression analysis than the SUI model (Figs. 2-4).

B.Some More Statistical Analyses

In Fig. 5, cdf (cumulative distribution function) of the prediction error for path loss of different models for BTW site is plotted. From the cdf plots for different base station, the median errors have been deduced. The prediction errors of the COST-231 Hata and the ECC model (median value of 6.0dB and 10.0dB) are closer to LS regression (median value of 4.0) than those of the SUI and the ITU-R NLOS models (median value of 20.0 and 24.0dB) (Fig. 5). A comparative analysis is shown in Table III. The cdf curve for LS regression and COST-231 Hata follow the Poisson distribution (λ=5.6604, λ=6.4203) while SUI (n=23, p=0.52747), ITU-R (NLOS) (n=49 p=0.66592) and ECC (n=5, p=0.35538) follow the negative Binomial distribution [17].

IV.CONCLUSIONS

An experimental campaign was conducted in the dense urban region of Mumbai using WiMAX transmissions at 2.3 GHz, for seven base stations. The observed signal levels have been converted into path loss values and plotted as a function of distance. These were compared with the various prediction methods, namely, COST-231 Hata, ECC, SUI, ITU-R (NLOS) as well as with the least square regression method. The path loss exponents, the ME and the SD of all the methods have been deduced and compared with measured values. The cdf values of prediction errors have also been compared. The different statistical parameters have been deduced and the best fit distribution for the cdf curves has been found. The prediction errors of the SUI and the ITU-R NLOS models are considerably higher than those of the COST-231Hata and the ECC models. The Poisson distribution is the one that best represents the statistics of the prediction error for regression analysis and for the COST-231 Hata model, whereas the other models follow the negative binomial distribution. The COST-231 Hata and the ECC methods give a good agreement with the measured data than the other methods.

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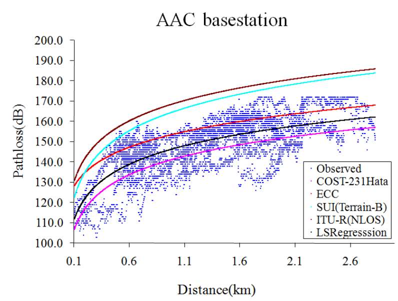

Fig.2 Comparison of observed path losses with those predicted from different models for AAC

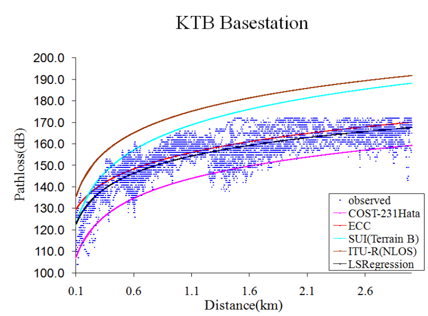

Fig.3 Comparison of observed path losses with those predicted from different models for KTB

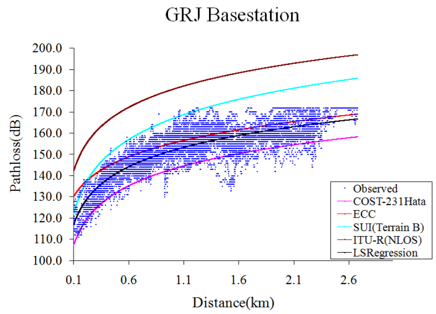

Fig.4. Comparison of observed path losses with those predicted from different models for GRJ

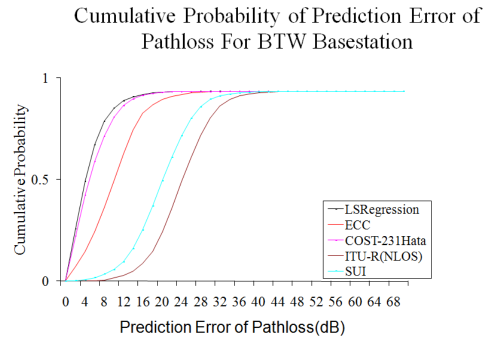

Fig.5. CDF of prediction error of path loss of BTW site.

TABLE I

EXPERIMENTAL DETAILS OF BASE STATIONS

S.No.	Site Name	Height of transmitting antenna	Other details	
1.	Ajay-Amar (AAC)	37m	Height of receiving antenna	1.5m
2.	Arihant (AHT)	32m	Transmitted power	43dBm
3.	Bootwala Bldg(BTW)	46m	Average Height of building [11]	25m
4.	Khetan Bhaban (KTB)	31m	Average street width [11]	15m
5.	Giriraj (GRJ)	28m	Average separation between buildings [11]	30m
6.	Jeevan Dhara (JVD)	27m	Street orientation angle [11]	90 degrees
7.	Obelisk (OLK)	30m	Correction for shadowing [1], [10]	9dB

TABLE II
ERROR PREDICTIONS COMPARED WITH LS REGRESSION ANALYSIS FOR DENSE URBAN ENVIRONMENT

Sites	LS		COST-231 HATA			ECC			SUI			ITU-R (NLOS)		
	n	*σ (dB)*	*n*	*μ (dB)*	*σ (dB)*	*n*	*μ (dB)*	*σ (dB)*	*n*	*μ (dB)*	*σ (dB)*	*n*	*μ (dB)*	*σ (dB)*
AAC	3.5	8.6	3.5	5.1	8.6	3.2	-7.3	8.8	4.2	-18.6	8.8	3.8	-22.3	8.6
AHT	6.0	5.6	3.5	3.5	7.6	2.7	-10.4	8.8	4.3	-18.3	6.6	3.8	-28.8	7.2
BTW	3.3	6.0	3.4	3.3	5.9	3.2	-9.5	6.0	4.1	-19.5	6.5	3.8	-23.7	6.2
KTB	3.0	5.5	3.5	9.9	5.9	3.3	-2.3	5.9	4.4	-15.7	7.6	3.8	-21.5	6.3
GRJ	3.4	5.9	3.5	8.8	5.9	3.3	-3.7	6.2	4.4	-15.2	6.4	3.8	-28.8	5.9
JVD	3.8	5.8	3.6	9.8	5.8	3.3	-2.5	6.3	4.6	-14.6	6.1	3.8	-29.9	5.8
OLK	4.1	6.8	3.5	13.84	7.0	3.3	19.6	8.1	4.4	-9.6	6.8	3.8	-18.2	6.8

TABLE III
STATISTICS DESCRIPTION COMPARED WITH LS REGRESSION ANALYSIS FOR DENSE URBAN ENVIRONMENT

Models/Values	LS regression	COST-231 HATA	ECC	SUI	ITU-R (NLOS)
Mean (dB)	5.66	6.42	10.83	20.61	24.73
Variance (dB)	14.10	17.52	30.47	39.07	37.14
Std. Error (dB)	0.97	0.99	1.30	1.30	1.22
Skewness (dB)	1.53	1.29	0.57	0.06	0.04
Excess Kurtosis (dB)	3.28	2.66	0.49	0.41	0.61
Median value (dB)	4.00	6.00	10.00	20.00	24.00