

Coverage Probability Analysis of WiMAX Network under Additive White Gaussian Noise and Predicted Empirical Path Loss Model

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Abstract—This paper explores a detailed procedure of predicting a path loss (PL) model and its application in estimating the coverage probability in a WiMAX network. For this a hybrid approach is followed in predicting an empirical PL model of a 2.65 GHz WiMAX network deployed in a suburban environment. Data collection, statistical analysis, and regression analysis are the phases of operations incorporated in this approach and the importance of each of these phases has been discussed properly. The procedure of collecting data such as received signal strength indicator (RSSI) through experimental set up is demonstrated. From the collected data set, empirical PL and RSSI models are predicted with regression technique. Furthermore, with the aid of the predicted PL model, essential parameters such as PL exponent as well as the coverage probability of the network are evaluated. This research work may assist in the process of deployment and optimisation of any cellular network significantly.

Keywords—WiMAX, RSSI, path loss, coverage probability, regression analysis.

I. INTRODUCTION

IN order to deliver ubiquitous voice, data and multimedia services, RF planning is an inevitable requirement in designing a wireless network. The factors such as the geographical location of the terrains and their surrounding environment, the frequency band of operation, and the type of technology adopted by the network operators for providing telecom service etc., have an intense effect in designing a wireless network [1]. In addition to these, different cities in the world progress towards establishing smart city, smart grid and Internet of things (IoT) based architecture [2], [3]. Due to this, the road widths, building heights, traffic scenarios, and terrain attributes like hills, foliage etc., are significantly changing throughout the city. The effects of these factors on the propagation characteristics of wireless channels are needed to be modelled precisely. The unpredictable signal propagation leads to non-optimal radio frequency (RF) planning resulting in huge capital expenditure (CAPEX), operational expenditure (OPEX), and poor quality of service (QoS) [4]. So, RF planning and network deployment in diverse terrains is a challenging task for designers. For this, the most important step is to estimate the precise PL model for the geographic region where the network is to be deployed. PL is calculated as the difference between the power transmitted from base station (BS) and the power received at the receiver

in logarithmic scale. PL model estimation is important as it affects the predictability of the coverage area, throughput, link budget, and outage probability of a wireless network. WiMAX is a wireless metropolitan area network (WMAN) technology that aims to provide triple play services such as voice, data, and multimedia for fixed as well as mobile users reliably. Due to the proficiency of this technology, it has been adopted for various fields of application. In [5], the authors demonstrated the feasibility of this technology in mobile telemedicine implementation. Also, the research works in [6], suggested optimum profile configuration of WiMAX and its usability for data aggregator in smart grid communication. So, it is an imperative requirement for estimating the accurate PL model which helps in proper WiMAX network planning for the deployed geographic region. In [7], a measurement campaign was conducted by AT Italy and Ericsson at University of Rome where a 3.5 GHz IEEE 802.16 network was operated. The PL exponent, probability distribution of absolute errors and link budget were estimated by analyzing the measured data. In [8], measurements were taken for a deployed 3.5 GHz WiMAX network in urban, suburban areas of Osijek, Croatia and the dependency of received signal level on the distances in both LOS and NLOS scenarios were explored. The research work in [9] facilitated the deployment of WiMAX technology for providing a broadband service in a seaport. In [10], the authors estimated the cell size, channel throughput of a 2.5 GHz WiMAX network by using COST-231 and SUI PL models. The research work in [11] dealt with how the effect of terrain irregularities, clutter distribution and human body affect the propagation characteristics of a 3.5 GHz WiMAX signal. The research work in [12] provided the analysis of PL exponents, standard deviations, mean errors and coverage predictions of 2.3 GHz IEEE 802.16 network deployed at different locations of a dense urban centre in western India. Here, it was found that Poisson distribution best suits for representing the statistics of prediction error for the network. The research work in [13] addressed the development of an appropriate PL model in an indoor environment serviced by a 3.3-3.6 GHz WiMAX network and explored the signal propagation loss due to different materials, human body etc. It was found that the insertion loss due to the thick walls and human beings are 12-15 dB and 7-18 dB, respectively. Here the propagation loss was measured with a bandwidth of 300 MHz. In [14], the authors predicted the PL model as a sum of sinusoidal functions and justified its accuracy for a 2.62 GHz fixed broadband network by using with statistical analysis. In

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[15], the authors observed the data transfer rate (DTR) and signal strength at the receiver in a 2.62 GHz fixed WiMAX network and also illustrated the cell coverage with changing the antenna tilt. It was found that down tilting the BS antenna by 1° and 2° extends the network coverage and capacity requirement by 97% and 100%, respectively.

From the literature survey, it is observed that the detail procedure for estimating the network coverage under the combined effects of additive white Gaussian noise (AWGN) and predicted PL model has not been addressed. Hence, in this research work the approach undertaken for coverage planning in a specific network is demonstrated.

The organization of this paper is provided as follows. Section II illustrates the background study. Section III provides the methodology for estimation of coverage probability. Section IV depicts the result analysis. Finally, Section V describes the conclusion.

II. BACKGROUND STUDY

A. Coverage Probability

It is defined as the probability that the received power at different locations in a cell exceeds certain minimum received power, P_{min} . In other words, it is calculated by finding the CDF of the received power at those locations. Mathematically, it is formulated as:

$$P_c = P(P_r(d) > P_{min}) \quad (1)$$

In general, the expression of coverage probability with PL and shadowing is represented as [1]:

$$P_c = Q(a) + \exp\left(\frac{2-2ab}{b^2}\right) Q\left(\frac{2-ab}{b}\right) \quad (2.a)$$

where the values of parameters a , b depend on the PL model and the network architecture considered for estimating the cell coverage and are provided below. In case of Log distance PL model, the value of a and b are given as:

$$a = \frac{P_{min} - (P_t + G_t + G_r - PL(d_0) - 10\gamma \log_{10}\left(\frac{d}{d_0}\right))}{\sigma} \quad (2.b)$$

$$b = \frac{10\gamma \log_{10} e}{\sigma} \quad (2.c)$$

B. PL Model

PL models are useful in estimating cell coverage, capacity and link budget in a wireless network. The link between BS and receiver in a wireless network is represented by a common log domain link budget equation and is written as:

$$P_r = P_t + G_t + G_r - PL - L_t - L_r - L_m \quad (3)$$

The Log distance PL model in a network is represented as:

$$PL(d) = PL(d_0) + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) \quad (4)$$

Taking into account the multipath effects due to obstacles and other effects, the PL model can be expressed as:

$$PL(d) = PL(d_0) + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \quad (5)$$

TABLE I
 LIST OF ABBREVIATIONS

Symbols	Meaning
P_c	Coverage probability
P_{min}	Minimum received power
P_t	BS transmission power
G_t	BS antenna gain
G_r	Receiver antenna gain
γ	PL exponent
σ	PL due to shadowing
L_t	Connector loss at transmitter side
L_r	Connector loss at receiver side
L_m	Other losses
y_i	Measured values of y
\hat{y}_i	Estimated values of y
\bar{y}_i	Mean value of y
d_0	Reference distance
d	Distance between BS and receiver

III. METHODOLOGY

In this approach, the different phases carried out for prediction of PL models are (i) Experimental measurement phase (ii) Statistical analysis phase (iii) Regression analysis phase. The objective of experimental measurement phase is to collect the relevant data throughout the network. For this, a geographic region near NIT Rourkela campus, Odisha, India was selected. The measurement campaign was performed in the month of April and the atmospheric temperature was calibrated between 32°C to 38°C. Here, the landscape comprises of buildings and trees with average height of 20-30 m and 10-15 m, respectively. From the geographic study, it was assessed that the signal from the BS was attenuated by compactly spaced buildings, and moderately planted trees, etc. The locations where the measurements were conducted cover both line of sight (LOS) and non-line of sight (NLOS) scenarios. The traffic was due to movable vehicles with speeds varying from 20-30 km/hr. The measurement set up for data collection is shown in Fig. 1. The equipment required for this are the customer premise equipment (CPE) or receiver, DC battery, laptop, and Ethernet cable. The CPE 'Gemtek WIXB-175' was employed here which is usually used for receiving signal in small and medium geographic area. It can capture the signal with carrier frequencies in-between 2.496 GHz to 2.69 GHz and it is required +12V DC for its operation. A laptop is used for data storage and visualisation of the CPE web page. An RJ-45 Ethernet cable of one meter length is used basically to connect the LAN port of the CPE to the respective port of

the laptop. It helps in transferring the measured data from the CPE to the laptop. For the purpose of getting the accurate location of the CPE and its distance from the BS, Google map software is used and it is installed in the laptop. The BS is configured with three vertically polarised directional antennas providing service coverage of 360°. The gain of each antenna is 14 dBi and the height of the BS is 30 m. The CPE is established at a height of 1.75 m from the ground throughout the measurement campaign. Table 2 illustrates the latitude, longitude and elevation distance of the locations in the concerned network where the data are collected. The location at 100 m distant from the BS is regarded as the reference distance and the whole measurement campaign is covered within 2000 m region surrounding the BS. The aim of the statistical analysis phase is to explore the mean and standard deviation from the collected data set which helps in predicting the behaviour of wireless channel, presence of coverage holes, attenuators throughout the network. The mean value provides the information about the average strength of signal and the standard deviation value indicates the depth of randomness of the channel at those distances. If the standard deviation value is more, then it indicates the fact that the channel responses at those distances vary significantly w.r.t. time. In statistical modelling, valuable information from the collected data is extracted by means of regression analysis. It helps in developing mathematical models which ease the understanding of the response of different complex system. Furthermore, regression analysis is used for predictive modelling of the measured data and is useful in building a mathematical model between the dependent and the independent variables.

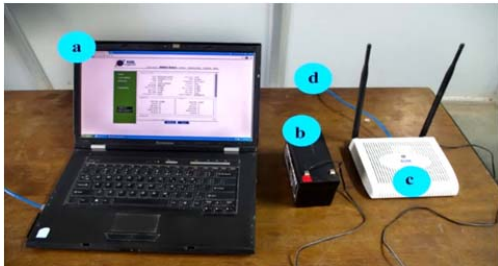


Fig. 1 Measurement setup (a) Laptop (b) +12V battery (c) CPE (d) RJ-45 Ethernet cable

The prediction model can be linear or non-linear. The former one helps in developing a linear relationship and the latter one in establishing non-linear relationship between the independent and dependent variables, respectively. For the measured data, it is possible to develop more than one predictive model but the question is how to choose the best among them. In general, least mean square method is used to determine the best model which accurately unveils the relationship between the variables. To explore this, the percentage of confidence interval for each of the models are analysed with goodness of fit parameters. The confidence interval measures the accuracy of the estimated coefficients in the predicted model. In general, 95% of confidence interval is

chosen which means that the probability of correctness of the estimated coefficients is 95%.

TABLE II
 LATITUDE, LONGITUDE AND ELEVATION DISTANCE OF THE MEASURED LOCATIONS THROUGHOUT THE NETWORK

Distance between BS and CPE in meter	Latitude (°N)	Longitude (°E)	Elevation Distance (ED) in meter
100	22.255	84.899	215.4
200	22.256	84.899	214.8
400	22.258	84.8997	212
600	22.26	84.899	208.9
800	22.261	84.9	205.3
1000	22.262	84.901	200.8
1200	22.263	84.901	203.1
1400	22.265	84.901	207.9
1600	22.267	84.901	206
1800	22.269	84.901	203
2000	22.271	84.901	204

The statistical parameters such as sum of squared errors (SSE), coefficient of determination (R^2), adjusted R^2 and root mean square error (RMSE) are used for determining the accuracy of the predicted models.

SSE: It measures the total deviation of the measured values of data from the fitted ones. It can be expressed as:

$$SSE = \sum_{i=1}^M \left(y_i - \hat{y}_i \right)^2 \quad (6)$$

R^2 : The coefficient of determination or R^2 specifies the square of the correlation between the measured and the predicted values of data. It is expressed as:

$$R^2 = 1 - \frac{\sum_{i=1}^M \left(y_i - \hat{y}_i \right)^2}{\sum_{i=1}^M \left(y_i - \bar{y} \right)^2} \quad (7)$$

In general, the value of this parameter lies between 0 and 1. For more precise prediction, a value closer to 1 of it is required. If the numbers of fitted coefficients are more, another parameter named Adjusted R^2 can be used for the analysis purpose. Its range lies between 0 and 1. For better accuracy, a value of it close to 1 is desired.

RMSE: This parameter illustrates the standard deviation of the random components present in the measured data set. It is expressed as:

$$RMSE = \sqrt{\frac{1}{M} \sum_{i=1}^M \left(y_i - \hat{y}_i \right)^2} \quad (8)$$

A value close to 0 of it is required for more accurate model.

IV. RESULT ANALYSIS

A. Prediction of RSSI Model

With regression analysis, the predicted RSSI model is given in (9).

$$RSSI = -33.15 + (-35.14) \log_{10} \left(\frac{d}{100} \right) \quad (9)$$

Fig. 2 shows measured RSSI data and its variation w.r.t. distance throughout the network. From the plot, it is observed that signal fluctuation is maximum at 1000 m and minimum at 400 m from the BS. It indicates that the randomness of the wireless channel is maximum at 1000 m from the BS. The accuracy of the predicted model is evaluated from Table III. As the values of SSE and RMSE are less, it signifies correctness of the predicted model. Further, the values of R^2 and Adjusted R^2 close to 1 also indicate the preciseness of the predicted model.

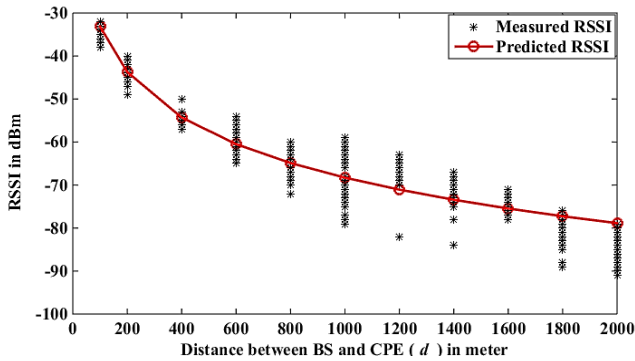


Fig. 2 Predicted RSSI model

TABLE III
GOODNESS OF FIT PARAMETER VALUES FOR THE PREDICTED RSSI MODEL

Predicted RSSI model	SSE	R^2	Adjusted R^2	RMSE
$-33.15 + (-35.14) \log_{10}(d/100)$	65.44	0.9704	0.9671	2.696

B. Prediction of PL Model

By using the regression analysis, the predicted PL model for the deployed WiMAX network is formulated

$$PL = 82.18 + 37.84 \log_{10} \left(\frac{d}{100} \right) \quad (10)$$

Fig. 3 represents the comparison of the predicted model with the standardised PL models like of COST-231 WI, Free space model, Ericsson model, SUI etc. The justifiability of the above model can be explained by analyzing the values of SSE, R^2 , Adjusted R^2 and RMSE with 95% confidence interval which are shown in Table IV. The value of RMSE is low which indicates the model has less prediction error. Also, the values of R^2 and Adjusted R^2 are close to 1 which signifies that the correctness of the predicted model approaches to 100%. Table 5 insights the RMSE values of the predicted model w.r.t the existing models. It is observed that the predicted model closely approximates with SUI Type A or

simply SUI A PL model as it has the lowest RMSE as compared to other models. The other PL models like COST 231 WI, Ericsson model etc. overestimate the PL for the deployed network.

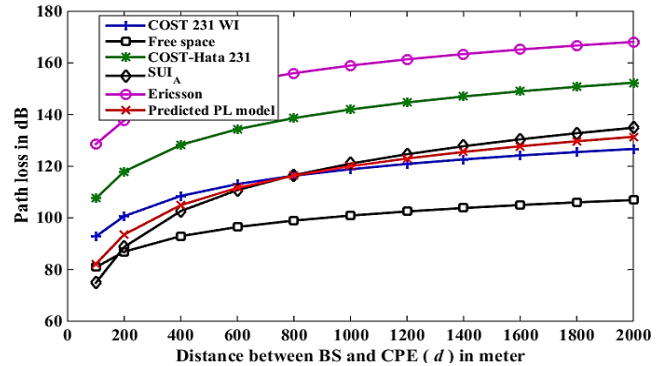


Fig 3 Comparison of predicted PL model with standardised PL models

TABLE IV
STATISTICAL PARAMETER VALUES FOR THE PREDICTED PL MODEL

Predicted PL model	SSE	R^2	Adj. R^2	RMSE
$82.18 + (37.84) \log_{10}(d/100)$	69.64	0.9685	0.9606	2.7817

TABLE V
RMSE OF STANDARDISED PL MODELS IN REFERENCE TO PREDICTED PL MODEL

PL models	RMSE (dB)
COST-Hata 231	11.28
COST-Hata 231 WI	7.77
Ericsson	18.04
SUI Type A	1.65

C. Coverage Probability vs. P_{min}

Fig. 4 illustrates the values of coverage probability w.r.t P_{min} of the considered WiMAX network by using the predicted PL model at different locations in the network, respectively. Table VI provides the values of parameters used in the simulation study. Table VII outlines the requirement of P_{min} for achieving various coverage probabilities at different distances from the BS. This analysis assists the network designer in deciding the P_{min} value at a particular distance from the BS for targeting certain coverage probability. From the graph, it is observed that for a certain distance from the BS if P_{min} is decreased, then the coverage probability is increased. For example, at a distance of 1000 m from the BS, the values of P_{min} have to be set as -81 dBm, -86 dBm, -95 dBm for attaining coverage probability of 90%, 95% and 99%, respectively. Furthermore, for a particular P_{min} , the coverage probability decreases with positioning the receiver far away from the BS. For example, for a P_{min} value of -80 dBm, the coverage probability decreases from 99% to 60% as the receivers' locations increase from 400 m to 2000 m w.r.t the BS. Also, for targeting specific coverage probability, as the distance between the BS and receiver increases, the requirement of P_{min} decreases. For example, for targeting coverage probability of 90%, the P_{min} value decreases from -69 dBm to -95 dBm as the distance increases from 400 m to

2000 m, respectively. So, it is imperative to decide the P_{\min} value for targeting certain coverage probability in designing any cellular network.

D. Coverage Probability with Variation of Modulation Techniques under AWGN and Predicted PL Model

The performance of coverage probability under the combined effects of AWGN and predicted PL model with varying the modulation/coding techniques is shown in Fig. 5. It is observed that for certain coverage probability, the network coverage is highest for QPSK $\frac{1}{2}$ and lowest for 64 QAM $\frac{3}{4}$. For example, with 90% coverage probability, the cell coverage estimated for QPSK $\frac{1}{2}$ and 64 QAM $\frac{3}{4}$ are 2000 m and 800 m, respectively. Table VIII provides the achievable network coverage for different coverage probability requirements considering the modulation/coding techniques.

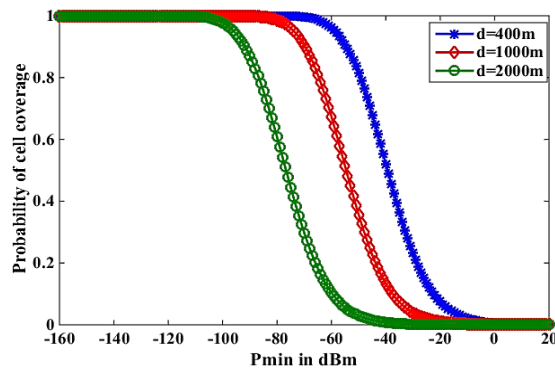


Fig 4 Coverage probability vs. P_{\min}

TABLE VI
NETWORK PARAMETERS CHOSEN FOR LINK BUDGET ANALYSIS

Network parameter	Value
P_t	43 dBm
G_t	14 dBi
G_r	8 dBi
L_t	9 dB
L_r	4 dB
L_m	6 dB

TABLE VII
REQUIREMENT OF P_{\min} VALUE AT DIFFERENT DISTANCES D FOR VARIOUS COVERAGE PROBABILITIES CONSIDERING PREDICTED PL MODEL

Coverage probability	$d=400$ m	$d=1000$ m	$d=2000$ m
90 %	- 69 dBm	- 81 dBm	- 95 dBm
95 %	- 73 dBm	- 86 dBm	- 100 dBm
99 %	- 82 dBm	- 95 dBm	- 109 dBm

TABLE VIII
ESTIMATED NETWORK COVERAGE WITH VARIOUS MODULATION AND CODING TECHNIQUES UNDER AWGN CHANNEL AND PREDICTED PL MODEL

Coverage probability	QPSK 1/2	QPSK 3/4	16 QAM 3/4	64 QAM 2/3	64 QAM 3/4
99%	900m	800m	500m	400m	300m
95%	1500m	1300m	900m	700m	600m
90%	2000m	1700m	1100m	900m	800m

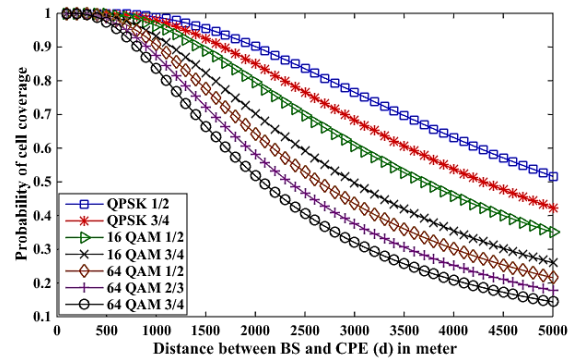


Fig 5 Coverage probability with modulation/coding techniques under AWGN channel and predicted PL model

V. CONCLUSION

In this paper, coverage probability analysis is performed under the combined impact of AWGN and predicted PL model of a 2.65 GHz WiMAX network deployed in a sub-urban area. For this, the detail procedure of PL modelling is discussed. The RSSI and PL models for the network under study are predicted and their preciseness are examined through analysing the goodness of fit parameters associated with them. The predicted PL model is compared with the standard PL models available for the typical wireless scenario and it is noticed that it closely approximates to SUI A PL model. The PL exponent for the network is obtained as 3.78. Furthermore, the coverage probability of the network in interest is analysed with the AWGN and predicted PL model. The above procedure and analysis can assist the network designer significantly for deploying any cellular network. In future work, more accurate techniques can be adopted with applying more robust data pre-processing, data analysis algorithms for the development of PL models which improve the preciseness of any cellular network planning and deployment process.

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