Macrocellular Propagation Prediction for Wireless Communications in Urban Environments

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ABSTRACT

In this paper, the signal propagation characteristics of urban environments are predicted by modeling important propagation parameters of the Code Division Multiple Access (CDMA) network for macrocells. The MOPEM propagation model has been selected as a model of choice due to its robustness in handling urban parameters. The model is simulated with some modifications using empirical data from the Visafone CDMA gathered from the Nigerian Telecommunications Limited (NITEL), Uyo, Nigeria and data from the field. From the simulation, we observe that propagation model parameters such as orientation angel, street width, building height, among others, has great influence on the system performance of CDMA wireless networks. We hope that with this research, systems designers could approach the installation of radio frequency equipment with some degree of confidence that the transmission link will effectively work, especially in urban areas.

Keywords: Signal propagation, Macrocells, Propagation path-loss, CDMA

1. INTRODUCTION

Wireless communication technology has become widespread and has encouraged useful researches in nearly all fields of human endeavour. Cellular services are today being used by millions of people worldwide. This technology has exponentially increased the network carrying capacity of wireless services, thus increasing the demand for the integration of a variety of multimedia services. These services include short massaging (SMS), voice, data and video. As a result, the bit rate required for the services vary widely from 1.2 Kbps for paging to several Mbps for video transmission. Also, supporting such wide range of data rates with a flexible mobility management, dramatically increase the network complexity.

To effectively dimension and rollout a cellular network, accurate site specific field strength models are required. Traditionally, operators make use of high-speed statistical propagation models for each proposed base site. Today's advanced cellular networks place greater emphasis on urban macro-cellular deployment. It is well known that statistical models perform poorly in such environments. To overcome this, empirical propagation models have found favour in both research and industrial communities owing to their speed of execution and their limited reliance on detailed knowledge of the terrain [1].

The Code Division Multiple Access (CDMA) technology emerged as an alternative to the GSM cellular architecture and has contributed to the last decade's explosion in the wireless market [2]. The development of efficient transmission, operation and management technologies and a progressive reduction in the size of the cells requires greater precision on the estimations of the system coverage, which is given by propagation loses in order to obtain total coverage with which the operator attempts to assure good quality of service (QoS). For this reason, a precise model of coverage [3] with easy implementation is required. In CDMA, due to its universal cell frequency re-use, cell capacity is mainly limited by the interference, so as to maximize the network capacity. Interference information is usually obtained from propagation models [4]. Additionally, the design of adaptive antenna structures relies on the availability of accurate spatial channel information.

Time dispersion also has a significant performance effect especially in high bandwidth digital systems and should therefore be accurately modeled. In this paper, an integrated propagation model for macrocells which covers large and predominant low building densities with a support for low medium traffic densities will be developed. Macrocells correspond to cells where the base station is placed above tall buildings or towers miles. The physical propagation environment in macrocells is characterized by near-ground irregularities (buildings, terrains, etc) [5].

Macrocells can be divided into different channel types: urban, suburban and rural. In urban environments, the probability of an elevated subscriber unit is greater. Therefore, the impact of the subscriber unit interference sources on the microwave receiver will be more substantial than in the residential area [6].

Wireless systems performance is affected by various theories. These include path-loss variation and distance, random slow shadowing, random multi-path fading, inter-symbol interference (ISI), co-channel interference as well as multi-user interference and background noise [7].

For urban propagation, three distinct models can be used. These include propagation in microcells, macrocells and indoor or picocells. For macrocells, as stated earlier, the base station is often place well above an average rooftop, while for microcells the base station is placed well below the average rooftop. For microcells, reflections and diffractions from the buildings and streets often dominate the propagation environment. The ray tracing type simulation models are adequate and justifiable for this type of models. For picocells (indoor propagation models), new challenges appear and improved propagation models and simulation tools are required to achieve reliable, accurate and computationally efficient propagation prediction models and help overcome many of the indoor propagation impairments.

2. STATEMENT OF THE PROBLEM

The evolution of cost-effective, high-quality network models require flexible utilization of available resources. With the need for high speed wireless data and increased frequency congestion, there is considerable interest on proper understanding of the radio propagation channel. Knowledge of radio wave propagation characteristics is vital for designing any wireless communication system in a given region. However, it is difficult to find a methodology of signal prediction which achieves the precision-complexity-time paradigm. Even more, the aim of finding a signal methodology for any urban environment is inadequate because it is obvious that the performance of a system is related to the propagation area. In some cases, a simple and fast method is enough, while in others, depending on the topology and morphology of the city, it is necessary to use more precise as well as efficient models.

3. EXISTING MODELING TECHNIQUES

Propagation models can be broadly categorized into three: empirical, deterministic and stochastic. Empirical models are those based on observations and measurements. These models are mainly used to predict the path-loss [8]. The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power propagation at a particular location [9].

Empirical models has two sub-categories namely, time dispersive and non-time dispersive [10]. The former is designed to provide information relating the multi-path delay spread of the channel. Examples of this class of models are the Stanford University Interim (SUI) channel models developed under the Institute of Electrical and Electronic Engineers (IEEE) 802.16 working group [11]. Examples of non-time dispersive empirical models are ITU [12], Hata [13] and COST 231 [14].

Although these propagation models for mobile systems have been comprehensively validated, it is however difficult to find a methodology of signal production which achieves the precision-complexity-time paradigm. Even more, the aims of finding a simple methodology for urban environment is inadequate because it is clear that the performance of a system is closely related to the operational area [2].

In this paper, we examine the propagation behaviour of the CDMA channel attenuation in the frequency range of 824MHz to 900MHz. The proposed model bases its initial analysis on the semi empirical propagation models by [14, 16-17]. Also, the model considers basic transmission loss composed of the free space loss, L_0, multi-diffraction loss, L_{mod} and the roof to street diffraction loss, L_{rts} as can be seen in the following equation

$$L_{COST\,231} = L_0 + L_{rts} + L_{msd} \qquad (1)$$

This model merges the contributions of [2, 16] by including a factor in the L_{rts} loss, which considers the orientation angle and the L_{msd} loss respectively. Due to the extrapolation properties to other areas and the applicability of the underlying hypothesis in the working environment, the COST 231 model is most appropriate for our study. This model was improved by an adjustment analysis of the distance, street orientation angle and mobile height. We shall in this paper consider the following parameters: frequency, distance, base station height, mobile height, street width, angle between the street and the propagation direction, buildings average height separation and terrain height.

Dependence on the Distance

It has been empirically verified that depending on the environment, there exist close relationship between the distance and the propagation loss. Furthermore, its influence on semi empirical models is so significant that a wrong evaluation would question all the later deductions.

Influence of the Variability of Terrain Elevation.
The dependence of the attenuation on mobile height, h_m, is a well known fact and has been extensively analysed in previous researches. However, the influence which varies in the model type, varies among authors. Models based on the two-ray theory,

establish a $-20log_{10}$ (h_m) dependence. Some empirical models derive dependencies fitted with measurements, for instance, [17] obtains a $-8log_{10}$ (h_m) law. In the empirical analysis, height dependence is derived through a calculus of the attenuation suffered on the diffraction edge, L_{rts}. The dependence obtained by these models due to the difference between the model and building heights (h_{roof}) is given as

$$L_{COST\ 231} = +20log_{10}\,(h_{roof}\ -\ h_m) \qquad (2)$$

The proposed model considers the dependence on height as shown in equation (3)

$$Kh_m\ log_{10}\,(h_{roof} - h_m) \qquad (3)$$

where Kh_m is a constant that determines the variation.

Dependence on the mobile's closest building height.

The use of the height of the nearest building to the mobile for h_{roof} is theoretically correct for an ideal urban environment. Nevertheless, it is inaccurate because in many cases the nearest building does not cause the diffraction, due to the existence of another building between the base station and the nearest building which obstructs the line of sight. The reflecting wave on the opposite building may not exist due to its low height or the existence of an excessively high diffracting building. This is not considered by previous models [14, 16] and it is part of the variability on a large scale which is observed in the measurement. On the other hand, other models propose a local average without any justification and arbitrarily on the selection of the area.

Dependence on the Mean Height of the Building

The models presented in [14][16] use the mean height estimator. Therefore, heterogeneity of local height is transferred to the great scale variability. They propose the evaluation of h_{roof} as the height of the highest building of each block. This evaluation criterion was based on urban consideration, since the most significant screens between the base station and mobile depends on the highest building.

Consideration of the Terrain Elevation: The analysis of the dependence on the mean height of the buildings proposed in [14] presents the deficiency of supposing flat terrain in the measurements of buildings height. In order to improve the model's precision, the heights are considered from a common reference level, like the sea level. In order to understand the influence of the terrain elevation, see Fig. 1.

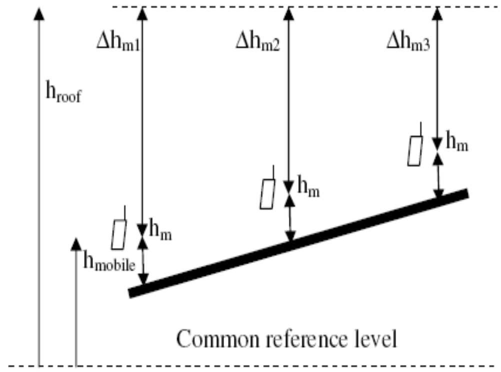

Fig. 1. Model considering homogenous height and terrain variation.

Mobiles on low areas are far from the average building height with greater diffraction angles. Thus, it is expected that the signal becomes lower and vice versa in the case of high area. The COST 231 model considers the variability of terrain elevation by including this parameter into equation (3), together with the estimation of the highest building's mean height of the working area, through the empirical adjustment of Kh_m.

Finite Multi-screen Effect: Through results obtained from the ray theory, the proposed model in [14] considers two rays arriving to the mobile. As shown in Fig. 2, the first one is the ray that is diffracted by the least building and arrives directly at the mobile. The second ray is diffracted in building and reflected by the building. The effect due to multi-screen diffraction is based on the analysis presented in [16], when the base station antennas are placed above the medium roof-top level of the surrounding buildings.

The buildings are considered as absorbent half screens of infinite width, with the same height as the buildings and infinitely small thickness. The positions of such screens are in the center of the buildings and are place perpendicularly to the propagation direction.

This geometric assumption simplifies the mentioned electromagnetic problems, but it does not consider the existence of the corners. As can be seen in Fig. 3, additional rays follow the criterion of diffraction or diffraction-reflection. Additional rays suffer diffraction on the edges placed at the corner and diffraction-reflection which occurs in the crossing of the streets. For this reason, the contribution is greater near the corners and is attenuated at the center of the street due to the distance these additional rays have to travel.

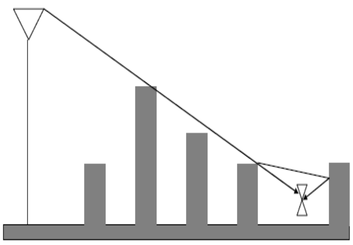

Fig. 2. Main rays considered by COST 231 model

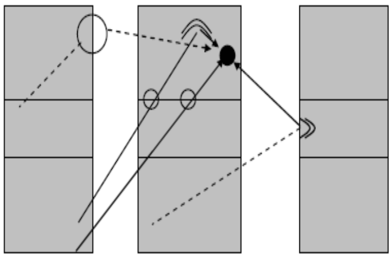

Fig. 3. . Main rays to be considered in the case of finite screens

Mobile

Main rays (1 diffraction or 1 diffraction – reflection)

Reflection

Addition rays (1 diffraction or diffraction – reflection)

Diffraction.

Dependence on the Angle between the Direction of Propagation and the Street Axis

The dependence on the street orientation particularly on the angle, θ, between the axis of the street and the propagation direction is a phenomenon that has already been studied [2, 14] and is confirmed by the measurements.

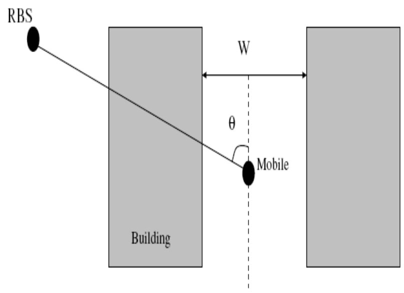

Fig. 4. Definition of the street orientation angle.

The proposed model in [15] considers the orientation angle when it calculates the diffraction on the edge of a diffracting building. The diffraction loss depend on the street orientation angle and can be evaluated through a calculus of the distance between the mobile and the building. In the worse case, taking the effective street width W' as:

$$W' = W/\sin(\theta) \quad (4)$$

and considering this evaluation with an orientation term [15] included, its formula in dB is given as:

$$10\log_{10}(\sin(\theta)) \quad (5)$$

This approach has not taken into account two important issues. For small angles, infinite signal levels could be predicted and the hypothesis of infinite screens under-estimates the propagation at the corners. Crossing streets are treated independently, although they have similar urban variables at the corners with the only exception of the orientation angle differing in 90^o to the additional contribution coming from the cross street with small angle at the corners. But a global incidence along the entire block and not only near the corner. For values near 0^o, infinite values are not predicted, so the theory comes closer to the real behaviour of the signal.

Dependence on the Distance to the Corner

The presence of corners allows additional contributions to the signal coming from crossing streets, due to the influence of additional rays. Therefore, a variation along the block is observed as being dependent on the distance traveled by these rays. This variation is an effect of the transition between the screening dispositions of both streets which emphasizes the continuity of the CDMA transmission signal. These empirical and theoretical reasons motivate the search of a term that models this phenomenon.

4. THE MOPEM PROPAGATION MODEL

The MOPEM propagation model was proposed by [2] in planning of cellular radio networks, but, the appropriateness of the model for CDMA wireless network performance has not been validated, hence this paper. The MOPEM propagation model is a summation of four independent terms, which describes the attenuation of propagation signals. These terms include: Loss due to free space propagation, L_0, Loss as a result of diffraction from the last building to the mobile street, L_{rts}, Loss due to the multi-screen hypothesis, L_{msd}, Improvement term due to finite multi-screen hypothesis, L_{esq}, and is given by:

$$L_{MOPEM} = L_0 + L_{rts} + L_{msd} + L_{esq} \quad (6)$$

The Free Space Propagation Loss Model, L_0

The free space propagation loss, L_0, is a function of the transmitting frequency, f, and the distance between the transmitter and the receiver, d. This is given by

$$L_0 = 32.44 + 20\log_{10}(d/km) + 20\log_{10}(f/MHz) \quad (7)$$

Loss due to Diffraction from Last Building to the Mobile Street, L_{rts}

The L_{rts} term takes into account the loss from the last diffracting building to the mobile receiver. Two improvements have been added to the term. These include terrain elevation included in the mobile and building height and a new function called the orientation angle. This parameter is defined below:

$$L_{rts} = 1.87 - 10\log_{10}(W/m) + 10\log_{10}(f/MHz) + 10.4\log_{10}(\Delta hm/m) + Lori_{MOPEM} \quad (8)$$

where the function of the angle is empirically found present in the polynomial

$$Lori_{MOPEM} = 2.8\left(\tfrac{\phi}{45}\right)^4 + 13.2\left(\tfrac{\phi}{45}\right)^3 - 29.5\left(\tfrac{\phi}{45}\right)^2 + 30.3\left(\tfrac{\phi}{45}\right) - 3.5 \quad (9)$$

and Δh_m is defined as

$$\Delta h_m = h_{roof} - h_{mobile} \quad (10)$$

Loss Due to Multi-Screen Diffraction, L_{msd}.

This term has been empirically fed with the distance to achieve higher accuracy of the MOPEM model. Thus,

$$L_{msd} = +54 - 18\log_{10}(1 + \Delta h_{base}/m) + [-4 + 0.7(\frac{f/MHz}{925} - 1) + 27.7\log_{10}(d/km) - 9\log_{10}(b/m) \quad (11)$$

where Δh_{base} is

$$\Delta h_{base} - h_{base} - h_{roof} \quad (12)$$

The buildings and the base station heights (h_{base}) are measured above sea level.

Signal Variation along the Block Due to the Finite Multi-Screen Effect, L_{esq}.

The L_{esq} term models the signal variation along the block due to the finite multi-screen effect and is given by the following equation

$$L_{esq} = -11.32 + 3.3(\log_{10}(d_{esq1}/m) + \log_{10}(d_{esq2}/m) \quad (13)$$

where d_{esq1} and d_{esq2}, are the distance from the receiver's location to each corners of the street. This expression is valid for the points that are placed farther than 7m from both corners.

Definition of Model Parameters

The following are the parameters definition of the MOPEM model.

Buildings height, h_{roof}: average of the heights of the tallest building of each block in the coverage area of sector, *m.*

Street width, *w*: the average width of the streets in the coverage area of the sector, *m*.

Buildings separation, *b*: estimated as half of the average length of the blocks in the coverage area of the sector, *m*.

Orientation angle, θ: defined by the street and the propagation as seen in Fig. 5.

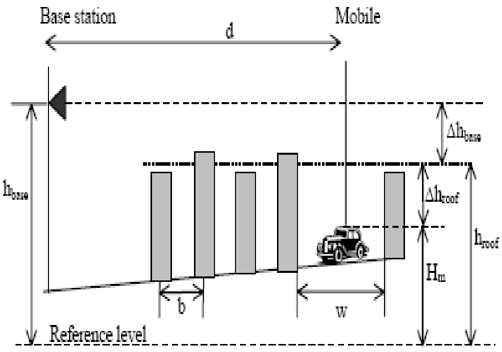

Fig. 5. Definition of the urban parameters.

5. DATA COLLECTION AND MODEL SIMULATION

This research requires practical data from the field to enable us obtain a reliable prediction of the signal propagation for urban environments. To this end, the Nigerian Telecommunication Limited (NITEL) at Dominic Utuk Avenue (former Brooks Street) was visited. Some data collected are data parameters measured at the control switch for the Visafone network, a CDMA system. Other parameters such as the roof height, building height, street width and distance from the receiver's location to each street corner, were measured directly from the field. The obtained data represents the average of various measurements. Table 1 shows practical data for various parameters of the MOPEM model for macrocells:

Table 1
Practical empirical data for the MOPEM Propagation Parameters

Parameter	Value
Frequency band, *f*	800MHz-900MHz
Orientation angle, θ	At Base station installation, 120° Between the discs, 45°–60°
Distance, *d*	1km-10km
Mobile Height, h_m	1.5m
Base Station Height, h_{base}	30m-50m
Roof Height, h_{roof}	4m
Building Height	13.3m
Mobile Street Width, *W*	8.4
Distance from receiver's location to each street corners, d_{esq1} and d_{esq2}	1km and 1.7km

The programming language used for the simulation is Visual Basic (VB) 6.0, an object oriented, event driven language suitable for scientific and database applications. Programming with VB, is a combination of visually arranged components or controls with attributes and code which provides additional functionalities for effective design of Graphic User Interface (GUI) applications. This program has a GUI for input of parameters and code for each simulation module. Simulation results are written to output (text) files.

Fig. 6 shows the Graphic User Interface which has four sections, each section obtaining parameters for each component of the MOPEM model.

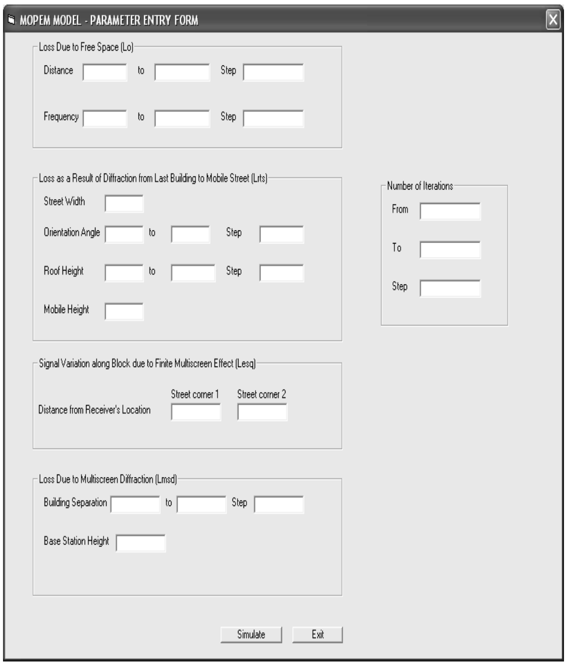

Fig. 6. The Simulation Program Form

To make our prediction accurate, we substitute some of the MOPEM parameters with the field data. The MOPEM propagation model represents a theoretical proof of concept that requires validation.

6. SIMULATION RESULTS

Fig. 7 shows a graph of path-loss versus distance between the transmitter and receiver antenna using the MOPEM model, for varying frequencies. As expected, path-loss increases as the transmitter-receiver separation increases. These losses are attributed to tall closely packed buildings and other obstacles. Logarithmic trend line equations are fitted to enable the prediction of new empirical results.

Fig. 8 demonstrates path-loss variations, with dependence on frequency and as the transmitter and receiver antenna separation (distance) is varied. This shows the classical dependence of signal level on frequency and distance. The plots show that the transmission medium is inherently lousier at higher frequencies. This is due to the absorption of Radio Frequency (RF) by various materials such as buildings, trees, water vapour, etc, which tends to increase with frequency. The frequency dependence in this case is also due to the decreasing effective aperture of the receiving antenna as the aperture of the receiving antenna and the frequency increases. This is intuitively reasonable, since the physical size of a given antenna type is proportional to the frequency. Because the plots are straight lines, linear trend line equations are fitted to enable the prediction of new empirical results.

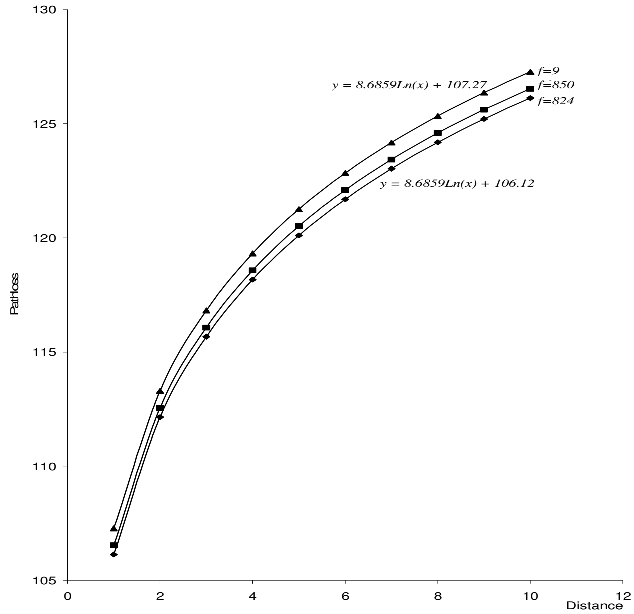

Fig. 7. A graph of path-loss vs. distance

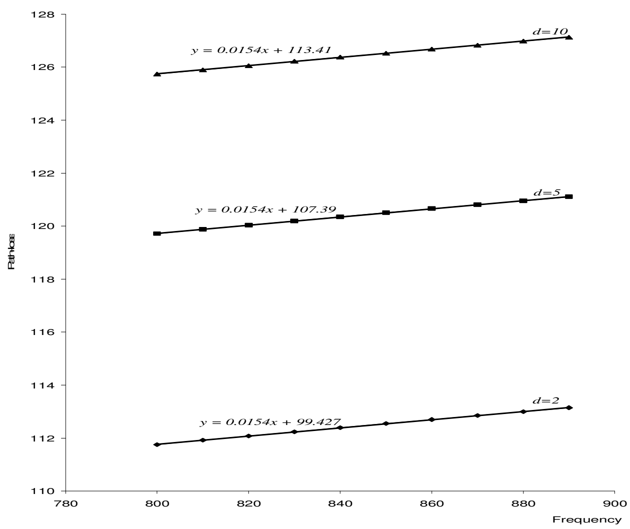

Fig. 8. A graph of path-loss vs. frequency, at varying distances

Fig. 9 shows a graph of path-loss vs. orientation angle. This figure proves that the rate of path-loss increases exponentially with the orientation angle. This is due to additional contributions from the cross street with small angles at the corners but with a global incidence along the entire block and not only near the corner. The figure also shows that for small angles, infinite levels could be predicted at the corner depending on the street considered. Since the signals are continuous in the passage from a street to another that crosses it, the orientation angle function must take into account this phenomenon. We fit an exponential trend line equation to enable the prediction of new empirical results.

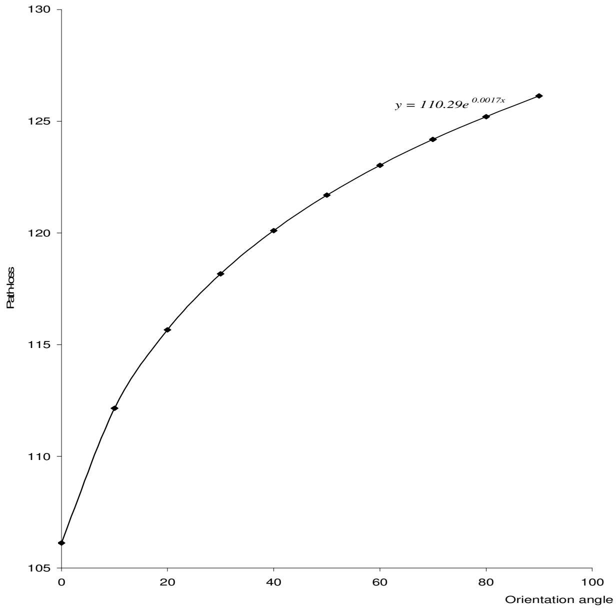

Fig. 9. A. graph of path-loss vs. orientation angle

7. CONCLUSION

Propagation modeling is a very useful component in cellular network planning of radio systems. In this paper, we considered a CDMA based propagation model for macrocells (urban areas) in the frequency band range of 800 MHHz-900 MHz, to provide a cost-effective, high quality transmission and effective utilization of its available resources. The model considers important propagation parameters such as frequency, distance, base station height, mobile height, street width, angle between the street and the propagation direction, buildings average height and separation, and terrain height.

We have been able to model important signal propagation parameters for CDMA macrocells system that minimize propagation losses, provide efficiency and predict signal propagation characteristics in an urban setting. We achieved this through a computer simulation of the propagation model. The simulated results were then used to interpret the relationship between the path-loss and other parameters of the model. The results validate the viability of the MOPEM Model in predicting signal characteristics for urban environments.

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Received: Nov. 2009. Accepted: Aug. 2010