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Base Line Knowledge on Propagation Modelling and Prediction Techniques in Wireless Communication Networks

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Abstract: One fundamental contributing factor to planning a workable and efficient wireless radio communication networks as well as improving existing ones lies on the ability to precisely predict the strength and coverage of radio signals between the transmitters and receivers in the system networks. The mathematical algorithms and tools used for these predictions are popularly referred to as propagation models. This research presents a detailed baseline surveyed of different types of propagation models and prediction techniques in cellular communication networks. Some of the key propagation models discussed include the Hata, SUI, Walfiscsh-Ikegami, Walficsh-Bertoni, Lee and ITU Models. The peculiar characteristics and limitations of the existing models has been shown. The research is completed by proposing an adaptive propagation prediction modelling algorithms which caters for stochastic signal attenuation phenomenon and the inhomogeneity of the spatial propagation channels.

Key words: Radio signals, propagation modelling, propagation models, adaptive propagation prediction, neural networks, channels

INTRODUCTION

A well designed cellular network structure is essential for effective roll out of any cellular mobile communication system. This is because a physical layer has to support the cellular design for every type of radio access technology (Rappaport, 2001). Hence, accurate and reliable models are vital for the prediction of radio channel qualities in the area for the deployment of the cellular mobile radio system. Traditional path loss models such as empirical, deterministic and semi empirical models have been used over the years. Empirical models are computational efficient but may not be enormously precise as they do not clearly account for a particular propagation phenomena. Also, deterministic models may be enormously precise but lack computational efficiency. Thus intelligent technologies such as Artificial Neural Networks (ANN), Fuzzy Inference Systems (FIS) and Genetic A0lgorithms (GA) has assured properties in solving optimizing tasks. Such properties include, ability of learning, modeling, classifying, obtaining empirical rules, solving optimizing problems, etc. This help to obtain prediction models that are more precise compared to traditional empirical models and more computational proficient than the conventional deterministic models. Path loss prediction in urban, sub-urban, open, outdoor and indoor environment have been successfully carried out using artificial intelligent systems (Ostlin and Uzuki, 2010; Popescu *et al*., 2006; Stankovic *et al*., 2004).

Literature review: A lot of research work has been carried out on the effectiveness of different path loss models. The researchers usually make an assessment based on the theoretical analysis using electromagnetic propagation idealized theories or by assessing the model that fits in through measurement data collected from the environment of interest or the combination of the two models. Practical lower bounds on the path loss prediction accuracy were provided using thirty propagation models presented over the years (Phillips *et al*., 2012). Measurement was carried out in different urban and open environment, however, it was concluded in the end that there is no particular considered path loss model that consistently predicted path loss. A comparative evaluation of five different path loss models using collected data from urban and suburban area at 910 MHz was presented (Delisle *et al*., 1985) with no conclusion on the particular model that offers the best result. Different path loss models for fixed wireless access system were compared (Abhayawardhana *et al*., 2005). This was based on the measurement carried out in

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Cambridge with the COST-231 Model, ECC-33 Model and the Stanford University Interim (SUI) Model showing the most guaranteed result. Studies on Path loss at UHF/VHF bands were carried out in Southern India where field strength measurement was taken at 200, 400 and 450 MHz and Hata model showed superiority over other considered models in all cases (Rao *et al*., 2000).

Propagation models for GSM 900 and 1800 MHz using modified Okumura and COST 231 Hata Models were developed for Enugu and Port Harcourt in Nigeria with the models fully adapted in the cities among other considerations and also made provision for rain attenuation and distinct features of the cities (Ogbulezie *et al*., 2013). Models representing the propagation characteristics in the NLOS situations with up to three intermediate vehicles were considered. The effectiveness of the models was verified by comparison of results from calculations made with the measured received power as a function of the height of the receiving antenna. Five propagation scenarios representing open, sub-urban and urban environment were investigated comparing the radio propagation characteristics at 700 and 2500 MHz relating to macro cellular coverage. The result showed the mean path loss with advantage at 700 against 2500 MHz and ranges approximately from 11-14 dB except for forested hilly terrain with the difference of about 18 dB.

Optimized path loss empirical model by means of proposed least square method was introduced by the researchers. The outdoor measurement taken in Cyberjaya, Malaysia was used in path loss comparison with other considered models. The optimized Hata Model offered a better performance as its relative error is lowest in comparison to other models. The researcher presented three propagation models for sub-urban area revealing the least path loss with Okumura Model and the highest path with COST-231 model for a particular transmission distance. Milanovic *et al*. (2007), SUI Model was used by the researcher in path loss calculation in three different terrains (open, sub-urban and urban area). Parameters from different terrain were analyzed. The path loss behavior of propagation models was presented by Sharma *et al*. (2011), proposing a better prediction using semi-empirical Model (Walfisch-Ikegami). Path loss was estimated using five different models; Hata Okumura Model, ECC-33 Model, COST-231 Hata Model, Stanford University Interim (SUI) Model and the Ericsson Model (Pardeep *et al*., 2014). ECC-33 showed a better prediction result for sub-urban area over other models. Imranullah *et al*. (2012), analysis of the performance of various path loss models was carried out by the researcher in different environments for wireless network. It suggested the use of SUI Model as a preferred model as a result of lesser path loss value with 10% difference at reduced receiver antenna height for sub-urban and open areas when compared to other model reviewed in the research with reference to free space estimated value. However, the research concluded that the use of a particular model for path loss estimation at various antenna heights in all areas is not ideal.

The efficiency of Okumura-Hata Model was investigated using a GSM base station operating at 900 MHz in a sub-urban area of the Northern part of Nigeria (Shoewu and Adedipe, 2010). On comparison of the measured results from the field with the Okumura-Hata Model for open and sub-urban area, the result obtained showed the least variation with Okumura-Hata Model for sub-urban areas. Okumura Hata Model was optimized for outdoor propagation coverage in urban southern part of Nigeria using Code Division Multiple Access system (CDMA) at 800 MHz operating frequency (Isabona and Konyeha, 2013). This was developed by comparison of calculated path loss and collected measurements data using Hata, SUI, Egli and Lee Models within applicable CDMA frequency range. Based on small mean error and closest path loss exponent, Hata Model have a preference as a reference for path loss optimization when the measured path losses were compared. The application of the optimized model in Nigeria CDMA system showed more reliability for urban path loss calculation at 800 MHz frequency band. Ramkumar and Gunasekaran (2013), a novel path loss model to tackle propagation delay in LTE network was introduced. Different correlation factors were considered using the propagation algorithm for both the transmitter and receiver antenna heights. On comparison with the Friis Model, simulation result of the proposed propagation model for both uplink and downlink showed a decrease in propagation delay.

Path loss prediction in urban areas at GSM-900 band using fuzzy Adaptive Neural network Inference System (ANFIS) was presented. The two path loss prediction results were compared and based on the indicated error criterion, ANFIS gave less error than error obtained from Walfisch-Bertoni Model. Also, ANFIS does not require equality in building height and distance and therefore can be applied in areas of related characteristics to the considered area.

MATERIALS AND METHODS

Radio propagation models: Propagation model are set of algorithms, mathematical equation and diagrams that is used to convey the radio properties of a given environment (Neskovic *et al*., 2000). They are essential in

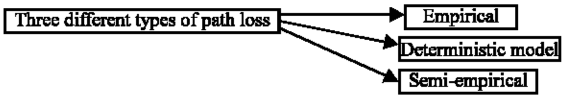

Fig. 1: Path loss models

Table 1: Basic path loss models

Models	Characteristics
Empirica	It is based on measurement data, uses statistical properties, well adapted to environment of any size, computational efficiency and simple. However, it has low accuracy
Deterministic	It is site specific and includes massive number of geometric data of the site. It needs high computational effort is highly complicated but has high accuracy
Semi-Empirical	It is established on combination of both empirical and deterministic models

carrying out interference investigation in the cause of deployment. The environmental overview of these propagation models is suitable for specific areas (open, sub-urban or urban area) or specific cell radius where electromagnetic signal propagates. In generally, a relationship exists between the propagation models and the environmental type most suitable for its application. The propagation model may be empirical, deterministic or a combination of empirical and deterministic models known as semi-empirical model. It can also be grouped into outdoor and indoor propagation models. The focus of this research is on outdoor propagation models. The three different outdoor propagation models are discussed in this study. These are the empirical, the deterministic and the semi-empirical models. Figure 1 shows the three path loss models and Table 1 shows the characteristic of each of the models.

Deterministic models: These are analytical models derived from electromagnetic propagation idealized theory, it is called deterministic because the same result is obtained for a given set of inputs. It has been widely applied in network simulators due to its usefulness in the computation of complex models with minimum loss. Every propagation situation depends on random components such as surveillance which is described in a predefined method by these models. This gives rise to a comprehensive path loss prediction that has nearly all propagation phenomena such as refraction, diffraction etc. The environmental properties such as obstacles positions or their materials have to be accurate for the prediction to be accurate. Some of the deterministic models are described.

Free space model: Electromagnetic wave signal strength loss due to line of sight path through free space is termed as Free-Space Path Loss (FSPL). Loss by two isotropic radiators in free space is represented by a power ratio. In this model, the existence of single path between the transmitter and receiver without barriers were assumed. A power ratio of 1.0 or 0 dB for the antenna gain is assumed and losses related with hardware imperfections or the effects of antenna gains are not included:

$$FSPL = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \quad (1)$$

Where:

λ = Signal wave length
(m) f = Signal frequency
(MHz); d = Distance from the transmitter
(m); c = The speed of light in a vacuum (2.99792458) $\times 10^8$ m/sec

However, this equation is only correct for far field at which it is assumed that spherical spreading is not to the transmitter:

$$PL_{free\,space}(dB) = 10\log_{10}\left(\left(\frac{4\pi df}{c}\right)^2\right) = 20\log_{10}\left(\frac{4\pi df}{c}\right) \quad (2)$$

$$PL_{free\,space}(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \quad (3)$$

where, distance (d) and frequency (f) is measured in km and MHz, respectively for a typical radio application. Therefore:

$$PL_{free\,space}(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 92.45 \quad (4)$$

For d (km) and f (MHz), the constant is 32.45; for d (m) and f (KHz), the constant is -87.55 and for d (m) and f (MHz), the constant is -27.55 (Kiran *et al*., 2015; Sklar, 2005) (Fig. 2).

However, the free space model is not often used alone but as part of Friis transmission equation which include antenna gain. A mathematical expression is proposed by Friis for transmission loss due to free space which defines the ratio relating to the received power $P_{rx}$and the transmitted power P_{tx} with respect to the effective area of the base station antenna A_{tx} mobile antenna A_{rx} the distance d (m) and the carrier wavelength λ.

In this model, the received power is a function of the transmitted power, the antenna gain and the transmitter-receiver distance:

$$\text{Transmission loss} = \frac{P_{rx}}{P_{tx}} = \frac{A_{rx}A_{tx}}{d^2\lambda^2} \quad (5)$$

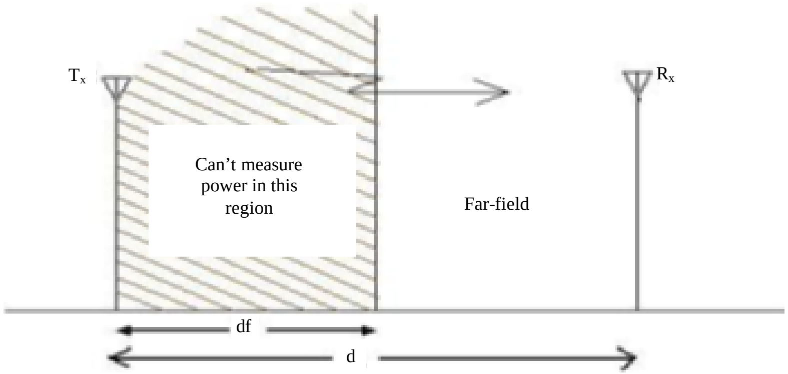

Fig. 2: Free space propagation model showing the near and far field

Equation 5 can be evaluated further for an ideal isotropic antenna:

$$\frac{P_{rx}}{P_{tx}} = \left(\frac{\lambda}{4\pi d}\right)^2 \tag{6}$$

For distance (km), frequency (MHz) and from the linear domain power unit (W) to log domain power unit (dBm), Eq. 6 gives Eq. 7 and 8, respectively:

$$P_{rx} = P_{tx} - 20\log_{10} d + 20\log_{10} f + 32.45 \tag{7}$$

$$P_{dBm} = 10\log_{10}\left(P_{mw}\right) \tag{8}$$

Two-ray ground reflection model: This model assumes the existence of two paths between the transmitter and the receiver for most propagation cases: a direct path and a reflected path (Joshi, 2012; Rappaport, 2002). Predictions using ray tracing method are good when the detailed information of the area is accessible, however the predicted result may not be applied to other locations. This makes the model site specific and mostly, typical indoor channel do not just have just two paths, therefore making the model just a theoretical model. The break distance is calculated:

$$d_c = \frac{4\pi h_{tx} h_{rx}}{\lambda} \tag{9}$$

where, h_{tx} and h_{rx} is the transmitting and receiving antenna height (m), respectively. Friis's equation is applied when the distance is shorter than this break distance and the modified path loss expression in Eq. 10 is used Fig. 3:

$$P_r = \frac{P_{tx} h_{tx}^2 h_{rx}^2}{d^4} \tag{10}$$

A slight stretch of two ray reflection model was proposed by Oda and Tsunekawa (1997) where the

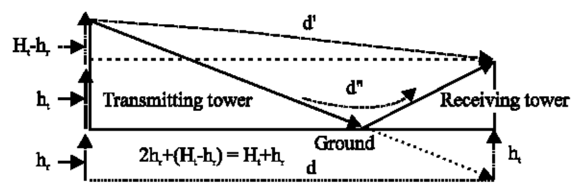

Fig. 3: Two ray reflection model

reflection of the plane over the minimal ground clutter and distance factor due to probability of collision was considered. Through adjustment of height offset (h_o) coefficient of Reflectivity (R) and the negative exponential factor, there may be a close modification of two-ray model making it appropriate for some type of measured data.

Ikegami Model: This deterministic model predicts field's strength at definite points by applying detailed map of building shapes, positions and heights. The limitations of trace ray paths as a result of single reflection from the wall accounts for diffraction calculation by application of single edge estimation and assumption of constant value for the wall reflection (Fig. 4). The two ray (reflected and diffracted) are power summed as:

$$L_E = 10\log_{10} f_c + 10\log_{10}\left(\sin\phi\right) + 20\log_{10}\left(h_o - h_m\right) - 10\log_{10} w - 10\log_{10}\left[1 + \frac{3}{L_r^3}\right] - 5.8 \tag{11}$$

where, Φ = angle amid the street-mobile direct line and L_r = loss due to reflection (0.25). Losses are underrated by the model (Ikegami) at large distance and frequency variation and in comparison with measurement (Ranvier, 2004).

Empirical models: The empirical models are close-fitted formulas of measurement data that gives a general description of channel behavior in the environment where

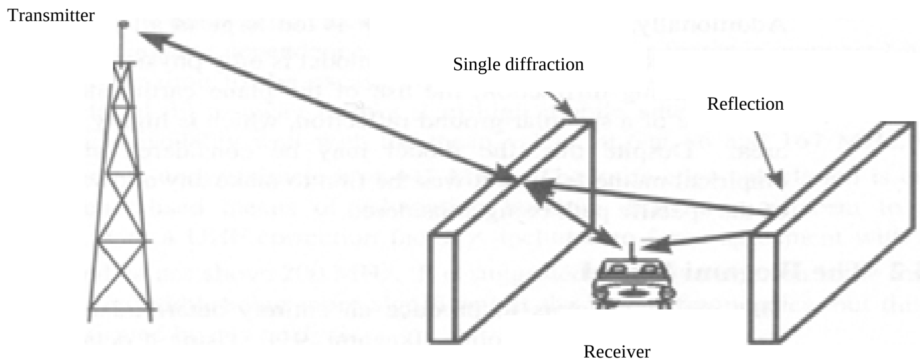

Fig. 4: Schematic geometry of Ikegami Model

the measurements were obtained. It predicts path loss between the transmitter and the receiver as a function of distance, considering a single path. The attenuation due to dipole antennas (dB) is given as:

$$PL_{dB}(d) = 10\alpha\log_{10}(d) + C \quad (12)$$

Where:

- α = Path loss exponent
- d = Distance (m) between the transmitter and receiver
- C = Constant which is dependent on parameters such as antenna type and frequency, etc

Empirical models do not compel the knowledge of the exact environmental geometry and as a result are simple to use, though they are not highly accurate. Some of the empirical models are discussed.

Okumura Model: This was developed by Okumura, a Japanese radio scientist, based on the measurements he obtained in and around Japan on environment clutter and irregular terrain. He discovered that simple power law is related to a good path loss profile with exponent μ as a function of antenna gain and frequency. The model was further classified into three models: for open, sub-urban and urban areas and selects different modes of computation depending on the complexity of the environment (in relation to population density). Okumura Model is suitable for urban area with many structures but with few tall structures and valid for frequency range of 150-1920 MHz over distance of 1-100 km and transmitter antenna height of 30-100 m. However, it can be extrapolated up to 3000 MHz (Anderson *et al*., 2009; Joshi, 2012). The model is stated as follows:

$$PL_{50\%}(dB) = LF + A_{mu}(f,d) - G(h_{tB}) - G(h_{rB}) - G_{arBa} \quad (13)$$

Where:

- $PL_{50\%}$ = The 50th percentile loss in propagation (median) value
- LF = Loss due to free space
- A_{mu} = Median attenuation relative to the free space
- $G(h_{te})$ = Gain factor for transmitter antenna height
- $G(h_{re})$ = Gain factor for receiver antenna height
- G_{area} = Environment type gain

Variation of $G(h_{to})$ and $G(h_{ro})$ with height. For height <3 m (variation at the rate of 20 dB/decade):

$$G(h_{tB}) = 20\log_{10}(hte/200) \ 1000\ m>hte>30\ m$$

For height <3 m (variation at the rate of 10dB/decades):

$$G(h_{rB}) = (10\log_{10}/3)hre<=3\ m;\ G(h_{rB}) = 20\log_{10}(hre/3)\ 10\ m>hre>3\ m$$

Okumura's Model is known to be one the simplest and best model when it comes to path loss cellular radio systems predictions. It is based entirely on measured data with no analytical explanation. However, its slow response to fast changes in terrain profile is a major demerit of this model. Due to realistic nature of this model, it has been developed into radio system planning standard in Japan.

Hata Model: This model is an advanced version of Okumura Model, also known as Okumura-Hata Model and commonly applied for path loss prediction for cellular transmission in built-up areas. It integrates data from Okumura Model and advances it to capture the impact of scattering, reflection and diffraction caused by structures in suburban, urban and open areas. This model is suitable for frequencies from 150-1500 MHz; distance of 1-20 km from transmitter to receiver; transmitter antenna height of 30-200 m and receiver antenna height of 1-10 m (Yuvraj, 2012). The path loss models for open, suburban and urban areas are expressed as follow:

Urban area:

$$PL_U(\text{Urban}) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_t) - a(h_r) + 44.9 - 6.55\log_{10}(h_t)\log_{10}(d) \quad (14)$$

Where:

PL_U = Urban areas path loss (dB)
h_t = Height of transmitter antenna (m)
h_r = Height of receiver antenna
$a(h_r)$ = Correction factor for receiver antenna height

Sub urban area:

$$PL_{50}(dB) = PL_{50}(\text{urban}) - 2\left[\log_{10}(f_c/28)\right]^2 - 5.4 \quad (15)$$

Open area:

$$PL_{50}(dB) = PL_{50}(\text{urban}) - 4.78(\log_{10} f_c)^2 - 18.33\log_{10} f_c - 40.98 \quad (16)$$

The correction factor for receiver antenna height:

$$a(h_r) = (1.1\log_{10} f_c - 0.7)h_r - (1.56\log_{10} f_c - 0.8)\ dB \quad (17)$$

For large city, the receiver antenna correction factor is:

$$a(h_r) = 8.29(\log_{10}\ 1.54\ h_r)^2\text{-}1.1,\ f<300\ MH_Z \quad (18)$$

$$a(h_r) = 3.2\ (\log_{10}\ 11.75\ h_r)^2\text{-}4.97,\ f \geq 300\ HM_Z \quad (19)$$

Hata model is not suitable for frequencies from 1800-1920 MHz micro cell planning when antenna is below the height of the roof and does not offer coverage outside 1500 MHz frequencies.

COST231 Hata Model-COST 231 Hata Model also known as Hata model PCS extension was formulated by the European Co-operative for Scientific and Technical research (EUROCOST). This model is an offshoot of Hata Model that has its origin from Okumura Model. It covers frequency from 1500-2000 MHz and is suitable for urban areas with the following characteristics: receiver antenna height of 1-10 m; transmitter antenna height of 30-200 m and a link distance of 1-20 km. The COST231 Hata Model for path loss is stated as follows:

$$PL_{50}(\text{urban}) = 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + (44.9 - 6.55\log_{10} h_t)\log_{10} d + Cm \quad (20)$$

Where:

f_c = The transmission frequency (MHz)
h_t = The transmitter antenna height (m)
d = The link distance between the base and mobile station (km)
C_m = The 0 dB for sub-urban and rural environment and 3 dB for urban environment
$a(h_r)$ = Receiver antenna height correction factor, a function of the size of the area of coverage

For small and medium sized environment; $a(h_r)$ (dB) is given as:

$$a(h_r) = (1.1\log_{10} f_c - 0.7)h_r - (1.56\log_{10} f_c - 0.8) \quad (21)$$

For Urban environment; $\alpha(h_r)$ (dB) is given as:

$$a(h_r) = 3.2(\log_{10}(11.75\ h_r))^2\text{-}4.97;\ f_c>400\ MH_Z \quad (22)$$

h_r = receiver antenna height (m). COST231 Hata Model is used for large cell mobile systems. However, it is suitable only when height of the transmitter antenna is above assured roof top (Chandan and Reshu, 2012).

ECC-33 Model: This is an extension of Okumura Model formulated by Electronic Communication Committee (ECC) in the European Conference of Postal and Telecommunications Administrations (CEPT) and the most widely used model based on Okumura model. Originally, the experimental data for Okumura Model was obtained from the outskirts of Tokyo, the developers segmented urban area into large and medium size cities and correction factors given for open and suburban areas. Giving that a highly built up area like Tokyo is relatively different from what is obtainable in a standard European suburban areas, the segmented urban area model for medium size city was suggested for European cities. Although, the Hata-Okumura Model is broadly used for UHF bands, it is uncertainly accurate for higher frequencies (Michael and Michael, 2014; Mollel and Kisangiri, 2014). Hence, the COST-231 Hata Model extends the frequency range up to 2000 MHz, however, it was designed for mobile systems with omni-directional receiver antennas sited <3 m above ground level. A different approach was considered in ECC-33 Model which extrapolated the novel measurements by Okumura and modified the assumptions in order to represent a closely wireless system. It is extensively used for urban settings in particular large and medium size cities. ECC-33 path loss model is expressed as follows:

$$PL = A_{fs} + A_{bm} - G_t - G_r \quad (23)$$

Where:
A_{fs} = Attenuation due to free space
A_{bm} = Media path loss
G_t = Transmitter antenna height gain factor
G_r = Receiver antenna height gain factor

These are independently defined as:

$$A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f) \quad (24)$$

$$A_{bm} = 20.41 + 9.831\log_{10}(d) + 7.89\log_{10}(f) + 9.56\left[\log_{10}(f)\right]^2 \quad (25)$$

$$G = \log_{10}\left(\frac{h_t}{200}\right)\left\{13.955.8\left[\log_{10}(d)\right]^2\right\} \quad (26)$$

For medium environment:

$$G_r = \left[42.57 + 13.7\log_{10}\left[\log_{10}(h_r - 0.585)\right]\right] \quad (27)$$

For large city:

$$G_r = 0.759h_r - 1.862 \quad (28)$$

Where:
f = Frequency (GHz)
d = The distance between the transmitting and receiving antenna (km)
h_t = The transmitter antenna height (m)
h_r = The receiver antenna height (m)

Plotting path los predicted with ECC-33 Model against distance on a log scale does not show a straight line (European Conference of Postal (CEPT). The analysis of the Coexistence of FWA Cells 2006).

Stanford University Interim (SUI) Model: SUI Model formulated by IEEE 802.16 Broadband Wireless Access working group in Stanford University is proposed for frequency band below 11 GHz containing the channel model. It is an expansion of Hata model with frequency greater than 1900 MHz used for path loss prediction in urban, sub-urban and open environments. The model is categorized into three different groups with each group having its own characteristics. These are group A-C. Group A is associated with a hilly environment that has moderate-to-heavy foliage densities and has the maximum path loss. It is suitable for compact populated urban area. Group B is associated with hilly environment with rare trees or flat environment with heavy or moderate tree densities. It is suitable for suburban area. Group C is associated with flat environment with light tree densities and has the minimum path loss (Noman *et al*., 2011). It is suitable for open area. Typically, the different groups are generally described as follows:

Cells <10 km in radius; receiver antenna height = 2-10 m, base station antenna height =15- 40 m and high coverage requirement (80-90%). The median path for the basic SUI model is expressed as:

$$PL = A + 10\gamma\log_{10}\left[\frac{d}{d_o}\right]X_f + X_h + S \quad (29)$$

Where:

$$A = 20\log\left(\frac{4\pi d_o}{\lambda}\right); \gamma = a - bh_t + \frac{c}{h_t}; d_o -$$
$$100\text{ m}, 10\text{ m} < h_b < 80\text{ m}; 8.2\text{ dB} < S < 10.6\text{ dB}$$

Where:
d = Distance between transmitter and receiver antenna (m)
λ = Wave length (m)
f≤ = 2000 MHz
γ = Path loss exponent
h_t = Height of transmitter antenna (m)
A = Free space path loss
S = A long normally distributed factor and a-c are constants
h_t = Determines the path loss exponent for environment type

In use frequency correction factors and transmitter antenna height are stated as follows:

$$X_f = 6.0\log_{10}\left(\frac{f}{2000}\right) \quad (30)$$

$$X_h - 10.8\log_{10}\left(\frac{h_r}{2000}\right); (\text{type A and B environment}) \quad (31)$$

$$X_h = -20.0\log_{10}\left(\frac{h_r}{2000}\right); (\text{type C envitonment}) \quad (32)$$

$$S = 0.65(\log_{10} f)^2 - 1.3\log(f) + \alpha \quad (33)$$

A = 5.2 for environment A and B and 6.6 dB for environment C.

Flat edge model: This model as proposed by Saunders and Bonar computes estimated knife-edge diffraction losses as a result of uniformly spaced buildings. This proffers a way out to the concept of propagation in built-up areas by assumption of equal building height and spacing (Saunders and Bonar, 1991; Saunders and Bonar, 1994).

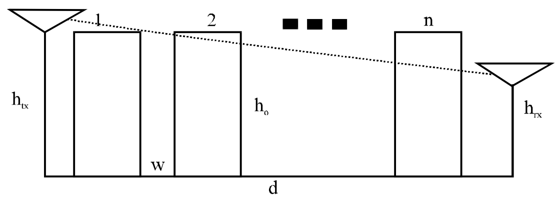

Fig. 5: Schematic link geometry of flat-edge model

Figure 5 the number of obstruction experienced in-between the transmitter and the receiver antenna is given as n, the link distance is w and h is the constant height. The model assumes a transmitter above or beneath series of obstacles that are of stable size and spacing and the receiver underneath the building top. Average values for the area under consideration are used or the values computed separately when there is significant variation in urbanization. The total path loss for flat-edge model is expressed as follows:

$$PL = L_n(t) + L_{FS} + L_E \quad (34)$$

Where:

L_E = Single edge diffraction above the last building
L_n = Multiple diffraction above the remaining (n-1) buildings
L_{FS} = Free space loss
L_n = a function of t and it is expressed as:

$$t = -\alpha\sqrt{\frac{\pi b}{\lambda}} \quad (35)$$

α (radians); b and λ (meters)

If $1 \leq n \leq 100$ and $-1 \leq t < 0$,then L_n can be calculated by following the approximate formula (Barclay, 2003)

$$L_n(t) = -20\log_{10} A_n(t) = -(C_1 + C_2\log_{10} n) \log_{10}(-t) - (C_3 + \log_{10} n)[dB] \quad (36)$$

where, C_1; C_2; C_3 and C_4 are 3.29; 9.9; 0.7 and 0.26, respectively. Diffraction for final building is computed from Ikegami Model (Ikegami *et al*., 1991).

$$L_E = 10\log_{10} f + 10\log_{10}(\varnothing) + 20\log_{10}(h_o - h_m) - 10\log_{10}(w) - 10\log_{10}\left(1 + \frac{3}{L_T^2}\right) - 5.8 \quad (37)$$

Where:

$\varnothing$ = Transmitter-receiver street-direct line angle
L_r = Loss due to reflection (0.25)

For large buildings in Flat-edge model, there is approximately the same path loss exponent with measurements (Ikegami *et al*., 1991).

Erceg-greenstein model: Path loss model for frequencies around 1.9 GHz was presented by Erceg *et al*. (1998) based on measurement using substantial set of data gathered by AT&T in the suburban areas of New Jersey. This model combines both median path loss and randomly distributed variation at some distance. It is expressed as:

$$PL = A + 10\left(\begin{array}{l} a - b * h_{tx} + \left(\frac{c}{h_{rx}}\right)\text{Log}_{10}\left(\frac{d}{d_o}\right) \\ +x10\log_{10}\left(\frac{d}{d_o}\right) + y\mu_\sigma + yz\sigma_\sigma \end{array}\right) \quad (38)$$

Where a, b, c, μ, σ_σ are fitted parameters for the three type of environments: type A is suitable for hilly environment with insubstantial tree densities; type B is suitable for flat environment with moderate-to-intense tree densities and type C is suitable for flat environment with insubstantial tree densities; A is the marginal path loss due to free space at some reference distance; x,y and z_r are random variables positioned between -2 and 2 (x lies between -1.5- 1.5).

Lee model: Lee model as proposed by W.C.Y Lee in 1982 is one the extensively used path loss models due to its simplicity and reasonable prediction accuracy. The model was originally derived for frequency in the region of 900 MHz but was later extended to 2 GHz for distance ranges greater than 1.6 km (Evans *et al*., 1997). Lee model is used in predicting area to area path loss and it specifies different parameters for varying type of environments. The model gives path loss relative to reference condition and is expressed as:

$$PL_{Lee} = P_{LO} + \beta\log_{10}\left[\frac{r}{1.6_{km}}\right] + 10\log_{10} + 10\log_{10}\left[\frac{f}{900\text{MHz}}\right] - \alpha_0 \quad (39)$$

$$\alpha_0 = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5$$

Where:

a_1 = (New transmitter antenna height (m)/30.48 m)
a_2 = (New reciver antenna height (m)/3 m)
a_4 = New transmitting antenna gain with respect to $\lambda_c/2$ dipol_B
a_3 = (New transmitter power/10 w)^2
a_5 = Receiver antenna gain correction factors

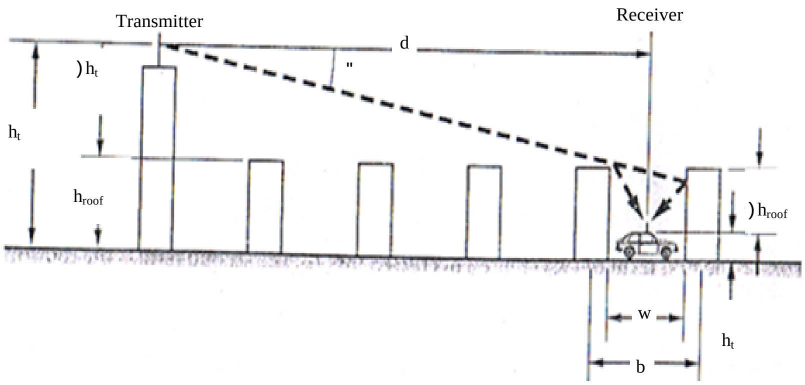

Fig. 6: Schematic diagram for COST 231 Walfisch- Ikegami denoting the parameters used in the model

n and ξ are based on empirical data with the values below: n = 2.0 for f_c<450 MHz (for urban areas). ξ = 2 for transmitter antenna height >10 m and 3 for transmitter antenna height < 3 m.

Semi-empirical models: Semi empirical model are based on the combination of empirical and deterministic models. It has the characteristics of both types of models. Some of the semi-empirical models are discussed as:

Walfisch-Ikegami Model: Walfisch-Ikegami model also known as COST Walfisch- Ikegami is a combination of Ikegami and Walfisch-Bertoni models developed by COST-231 project (Seybold, 2005). It considers only buildings in the vertical plane between the transmitter and receiver. It differentiates between two states, the Line of Sight (LOS) and the Non-Line of Sight (NLOS) and each of them is calculated differently (Fig. 6). The model formulation defining the path loss equation for LOS situation is expressed as follows:

$$PL_{los} = 42.6+26\log_{10} R+20\log_{10} f;\ \text{for } R \geq 20 \text{ m} \quad (40)$$

The path loss for non- LOS is defined as:

$$PL_{NLOS} = \begin{cases} L_{FS} + L_{rts} + L_{msd} \\ L_{FS} \quad \text{if } L_{rts} + L_{msd} > 0 \end{cases} \quad (41)$$

L_{FS} = Loss due to free space
L_{rts} = Roof top to street diffraction
L_{msd} = Loss due to multi screen diffraction

The grouping of the propagating signal along the multi-screen path into the street of mobile location is designated by L_{rts}:

$$L_{rts} = \begin{cases} -16.9-10\log_{10} w+10\log_{10} f+20\log_{10} \Delta h_r \\ +L_{ori}\ h_{roof} > h_r;\ \text{if } L_{rts} < 0 \end{cases} \quad (42)$$

Δh_t = h_t-h_{roof}
Δh_r = h_{roof}-h_r
(h_t = Transmitter antenna height
h_r = Receiver antenna height)

L_{ori} is defined as:

$$L_{ori} = \begin{cases} -10+0.354\phi \ \text{ for } 0 \leq \phi < 35 \\ 2.5+0.075(\phi-35) \text{ for } 35 \leq \phi < 55 \\ 4-0.114(\phi-55) \text{ for } 55 \leq \phi < 90 \end{cases} \quad (43)$$

The multi-screen diffraction loss L_{msd} is an integral approximated by Walfisch-Betoni Model and an answer to cases where the transmitter antenna height is taller than the average roof top. This was then extended by COST 231 to cases where the transmitter antenna height is shorter than the average roof top by the inclusion of empirical Eq. 44:

$$L_{msd} = L_{bsk}+K_a+k_b \log_{10} R+K_f \log_{10} f - 9\log_{10} b - 9\log_{10} f \quad (44)$$

$$L_{bsk} = \begin{cases} -18\log_{10}(1+\Delta h_t) \text{ for } h_t > h_{roof} \\ 0 \text{ for } h_t \leq h_{roof} \end{cases} \quad (45)$$

$$K_d = \begin{cases} 18 & \text{for } h_t > h_{roof} \\ 18-15\dfrac{\Delta h_t}{h_{roof}} & \text{for } h_t \leq h_{roof} \end{cases} \quad (46)$$

K_a = increase in the path loss for transmitter antenna shorter than the roof top of adjacent building:

$$k_a \begin{cases} 54 \quad ;\text{for } h_t > h_{roof} \\ 54-0.8\Delta h_t;\ \text{for } d \geq 0.5 \text{ km},\ h_t \leq h_{roof} \\ 54-0.8\Delta h_t\left(\dfrac{d}{0.5}\right);\ \text{for } d < 0.5 \text{ km},\ h_t \leq h_{roof} \end{cases} \quad (47)$$

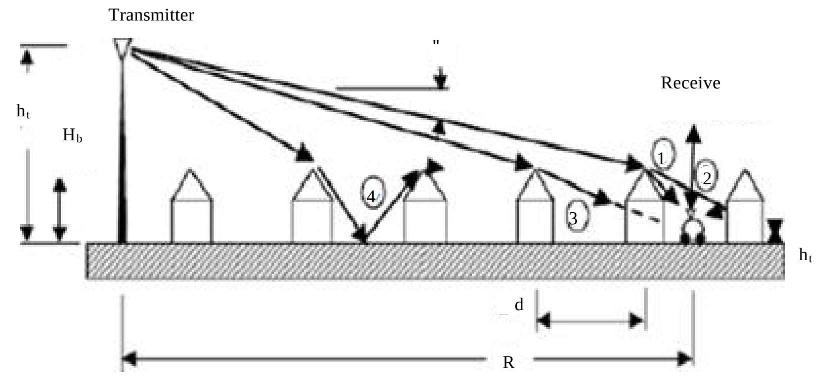

Fig. 7: Schematic diagram and parameters in the Walfisch-Bertoni Model

K_d K_f control multi-screen diffraction loss against distance and frequency. k_f for suburban with moderate-tree density and urban area are given in Eq. 48 and 49, respectively:

$$k_f = -4 + 0.7\left(\frac{f}{925} - 1\right) \quad (48)$$

$$k_f = -4 + 1.5\left(\frac{f}{925} - 1\right) \quad (49)$$

Where :

d = Distance between the transmitter and receiver (km)
f = Frequency (MHz)
R = Distance between buildings (m)
w = Street width (m)
ϕ = Direct path street incidence angle (degrees)

Walfisch: Ikegami Model is limited to urban environment and only inserts a characteristic value (Ikegami *et al*., 1991). The model is also restricted to urban environment (Doble, 1996). The model restrictions are given in Table 2-4.

Walfisch-Bertoni Model: This is a semi-empirical model developed by Walfisch Bertoni and takes into account the effect of diffraction from the top of the roof and building. It is suitable for an environment with uniform building heights and spacing. It assumes an elevated transmitter antenna realized by vertical plane wave approximation to compute buildings influence on the signal by the elevated antenna (Isabona and Azi, 2012; Joseph and Michael, 2013). Average signal strength using diffraction is predicted at street level using Walfisch-Bertoni Model Fig. 7.

Walfisch-Bertoni Model considers path loss resulting from three factors: the free space PL_{fs}, diffraction from the rooftop $PL_{roof\ top}$ and scatter loss from rooftop down the street PL_{down} Free space loss is given as:

Table 2: Geometric values for SUI Model parameters

	Environment		
Parameters	A	B	C
A	4.6.00	4.0000	3.600
$b(m^{-1})$	0.0075	0.0065	0.005
c(m)	12.600	17.1.000	20.000

Table 3: Parameters for Lee path loss for various environments at 900 MHz

Environment	L_0	β
Free space	80	20
New American sub-urban	89	4.35
North American sub-urban	101.7	3.85
North American urban	104	4.31
Japanese urban	124	3.05

Table 4: Limitations of COST 231 Walfisch-Ikegami Model

Frequency (MHz)	800-2000
Transmitter antenna height (m)	4- 50
Receiver antenna height (m)	1-3
Distance between the transmitter and the receiver (m)	20-5000

$$PL_{fs} = -10\log_{10}\left[\frac{\lambda}{4\pi r}\right]^2 \quad (50)$$

Diffraction and scatter loss from the roof top down the street is given as:

$$PL_{down} = \frac{\lambda_{\rho 2}}{2\pi^2 (H_b - h_r)} \quad (51)$$

Diffraction from the roof tops is given as:

$$PL_{roof\ tops} = P(g)^2 = \left[0.1\left[\sin\delta\sqrt{\frac{d}{\lambda}}\right]^{0.9}\right]^2 \quad (52)$$

where $\sin\delta = h_r\text{-}H_b/R$. The total loss can then be expressed as:

$$PL_{total} = \frac{5.51}{32\pi 4}\frac{(h_r - H_b)^{18}\rho_1 d^{0.9}}{(H_b - h_r)^2}\frac{\lambda^{21}}{E^{3.8}} \quad (53)$$

$$PL_t(dB) = P_T + G_T + G_R - L_T - L_R - RSS(\text{Measured}) \quad (54)$$

$$PL_{total} = 89.5 - 10\log_{10}\left[\frac{\rho_1 d^{0.9}}{(H_b - h_r)^2}\right] + 21\log_{10} f - 18\log_{10}(h_t - H_b) + 38\log_{10} R_K \quad (55)$$

Where:

$\rho_1 = \sqrt{\left(\frac{d}{2}\right)^2 + (11_b + h_r)^2}$

f = Frequency (MHz)
h_t = Height of transmitter antenna (m)
H_b = Building height
h_r = Receiver antenna height (m)
d = Buildings space (m)
R = Distance between transmitter and receiver

Terrain Models: Terrain is described as natural geographical characteristics of the land where electromagnetic signal propagates. Terrain Models compute losses due to diffraction along Line-of-Sight path (LOS) as a result of obstruction such as buildings or the terrain itself. The terrain features drastically affects the propagation of electromagnetic waves, even over moderate distances. Varied terrain produces diffuse multi-path, diffraction loss, shadowing and blockage. Median path loss is provided as a function of distance and terrain roughness by these models. Variations in media as a result of other effects are treated separately (Seybold, 2005).

ITU Terrain Model: The model is simple and computes path loss as a product of free space with a single diffraction due to the terrain ('ITU-R. Terrestrial land mobile radiowave propagation in the VHF/UHF bands. ITU-R, 2002 developed on the basis of theory of diffraction, path loss is predicted using ITU terrain model as a function of the blockage height and the first Fresnel zone. The model describes any impediment in-between telecommunication link and thus is fit to be used in cities and in open fields. It is valid in any terrain. Coverage frequency and distance and is expressed as:

$$A = 10 - 20C_N \quad (56)$$

$$C_N = \frac{h}{F_1};\ h_L - h_o \text{ and } F_1 = 17.3\sqrt{\frac{d_1 d_2}{f_d}}$$

Where:
A = Additional loss due to diffraction (in excess of free space loss) (dB)
C_N = Normalized terrain clearance
h = The difference in height (m) (it is negative in the case of LOS path being completely obscured)
h_L = Line-of-sight
h_0 = Obstruction height (m)
F_1 = First Fresnel zone radius
d_1 = Obstruction distance from one terminal (km)
d_2 = Obstruction distance from the other terminal (km)
f = Transmission frequency (GHz)
d = Distance between the transmitter and receiver(km)

ITU Terrain Model calculates the extra loss in every obstructed path, these are added together to the predicted path loss for line-of-sight and then computed using Friis transmission equation or an equivalent empirical or theoretical model. The model is considered suitable for losses above 15 dB and could be suitable for losses as low as 6 dB. It recommends the discard of a negative loss as a result of the blockage (which in reality is a gain) or any loss that is <6 dB. To correct the loss due to assumption of free space, the additional maximum loss is utilized.

Egli Model: The model predicts point-to-point link total path loss and is applied in outdoor line-of-sight propagation while presenting path loss as a single quantity (Egli, 1957). The Egli Model is typically appropriate for cellular settings that have a fixed and a mobile antenna. The model is also applicable to settings where the propagation goes over an irregular terrain, nevertheless, it does not consider travel through vegetative obstruction like shrubbery. Egli Model is usually appropriate for UHF and VHF spectrum transmissions. The model is given as:

$$P_{RSO} = G_T G_R \left[\frac{h_t h_r}{d^2}\right]^2 \left[\frac{40}{f}\right]^2 P_T \quad (57)$$

Where:
P_{R50} = 50th percentile receive power (w)
P_T = Transmit power
G_T = Total gain of transmitter antenna (dB)
G_R = Total gain of receiver antenna (dB)
h_t = Height of transmitter antenna (m)
h_r = Height of receiver antenna (m)
d = Distance from transmitter antenna (m)
f = Frequency of transmission (MHz)

Path loss, however is predicted as a whole using Egli Model and there is no further division of the loss into losses due to free space and other losses (Seybold, 2005).

Longley-Rice (LR) Model: This is also called an Irregular Terrain Model (ITM) and predicts radio signal attenuation in 20-20 GHz frequency range. LR Model is implemented in two configurations, prediction over an area and point-to-point link prediction. It offers a simplification of the received signal power, however, there is no detailed channel characterization. Statistical resources are used to recompense for the channel characterization, this is dependent on the variable from each environment and situation. Signal variation is ascertained using the model in accordance to free space, atmospheric and topographical changes. Statistical estimates are used to describe these variations that contribute to the overall signal attenuation. The statistical estimates variables of the prediction model vary with situation, time and location. The reference attenuation is determined as a function of the distance, urban area factor and attenuation variables (Seybold, 2005).

Artificial Neural Networks (ANN): Artificial neural network models consist of various neurons and nodes which are divided into various levels with connections in-between them. There may be various input signals to the neurons which are combined using suitable weights and passed through a precise transfer function. Training of the network must be done to specify various weights. Training is conducted using measured data and the ability of ANN to predict an unknown situation depends on the training process . The task of an ANN is to ascertain the most exceptional functional fit for a particular set of input-output pairs. It also interpolates and extrapolates unknown data sets. Some type of regression is required for satisfactory path loss prediction in different environment for both training error and error of unknown input minimization. Fundamentally, the most appropriate application of the feed-forward structure of the path loss is determined using the collected measurement data from the area under consideration. This section introduces the neuron model and the feed-forward network methods.

Neuron Model: Figure 8 represent a simple neuron model with input signals:

$$X = [x_1 x_2, ..., x_n 1]^T \tag{58}$$

Output of Eq. 57 gives:

$$u = W^T X \tag{59}$$

where $(.)^T$ represents the transpose and the weights of neuron W is given as:

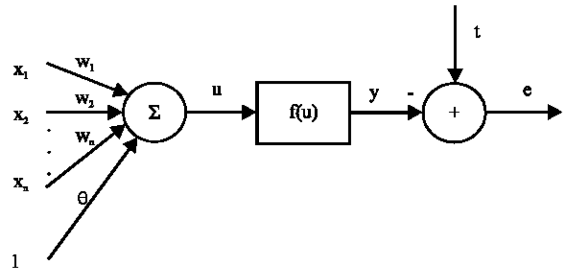

Fig. 8: Simple neuron model (Ostlin *et al*., 2009)

$$W = [w_1 w_2, ..., w_n \theta]^T \tag{60}$$

To present the possibility for shifting the activation function f(.) an extra scalar bias parameter θ is added to the weight to either the right or the left. The activation function can be some differential function and it is called the non-linearity of the neuron model. The generally used transfer function can be referred as the activation function and is defined as (Rojas, 1996):

$$f(u) = \frac{1-\exp^u}{1+\exp^u} \tag{61}$$

This condenses the output in the range -1 to 1. From Fig. 8, the output error of the neuron is computed by subtraction of f(u) from (t) .f(u) is the sigmoid output and (t) is the target value.

$$e = t - y \tag{62}$$

Neuron model helps in the minimization of the output error (e) in accordance with some optimization criteria such as squared error minimization.

RESULTS AND DISCUSSION

Feed-forward network: Feed forward network is an extension of the neuron model that consists of numerous layers that are hidden with each layer having various neuron and weight numbers (Rojas, 1996).

The neuron model and the feed forward multilayered vectors and weights are equivalently defined. The first hidden layer, the second hidden layer and the output layer have n_1, n_2 and n_3 neurons and weighted vectors $w^{[1]}$ $w^{[2]}$ and $w^{[3]}$, respectively with all containing a bias θ. The notation $ANN_{n0\text{-}n1\text{-} ,..., nk}$ from the feed forward network represent the input number, the neuron numbers in the first hidden layer and the neuron numbers in the output layer respectively. The ith activation function in the jth

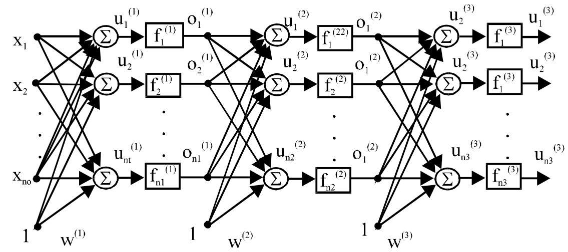

Fig. 9: Three layer feed forward artificial neural network architecture (Ostlin *et al.*, 2009)

hidden layer from Fig. 9 described as $f^{[j]}_i$ and $O^{[j]}_i$ denote the output from the ith neuron and the jth layer. The inputs, hidden layers and neurons number are selected in order for the model to be able to give correct estimation of the particular problem. A trade off exists between obtaining the complexity of the core function specified by the training data and ability of the model to generalize to new inputs (Hagan and Demuth, 1999).

Research gap: Although, a number of propagation prediction models are obtainable in the literature (like Free space, Okumura, SUI, Lee, COST 231, Walficsh-Bertoni, Walficsh-Ikegami Models, etc.), they are limited in one way or the order. For example, it is reported by Hagan and Demuth (1999 and Rumelhart *et al.* (1986) that there is built-in-error in the propagation models applied for macro cell mobile systems (the standard deviation is as large as 7-10 dB which in signal power is a factor of ten). One basic reason of the large built-in-error limitation of the existing models is due to dissimilar assumptions and different radio propagation environmental scenarios with which many of the models were developed. Any reduction in the above mentioned quantity of error will positively impact path loss prediction accuracy and the general cellular network coverage performance. Also, majority of the models needs building geometry or the terrain geometry under consideration and this makes their implementation cumbersome during network planning.

One robust way to address the limitations of the existing models is to develop an adaptive propagation prediction modeling algorithms which caters for stochastic signal attenuation phenomenon and the heterogeneity of the spatial propagation channels in different radio communication environment. Our research work is tailored towards adopting this approach by employing a hybrid neural model which combines existing models and an adaptive neural network modeling capabilities and uses the parameter estimation schemes to

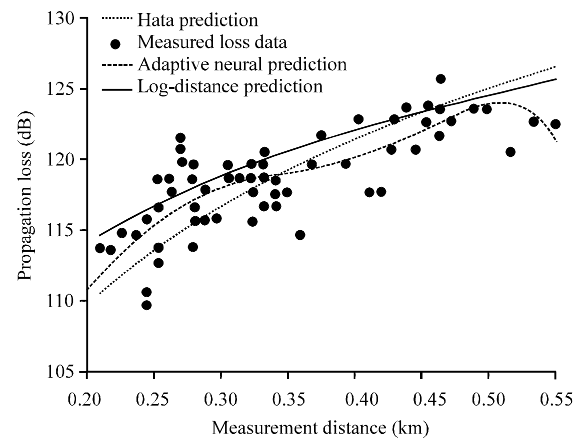

Fig. 10: Proposed model prediction and other models with measured Propagation loss data in location 1

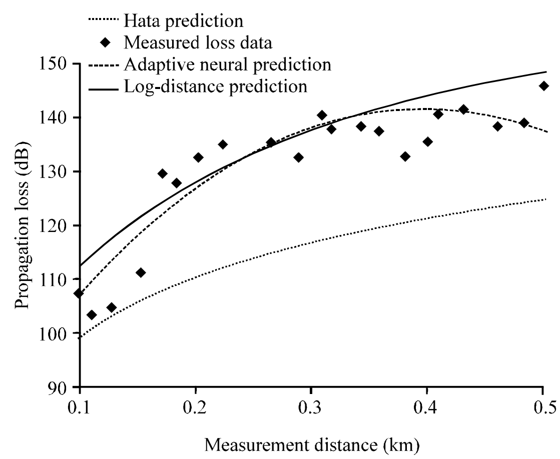

Fig. 11: Proposed model prediction and other models with measured Propagation loss data in

map the nonlinear single output variable representing the propagation loss. Figure 10 and 11 are preliminary results obtained after using the proposed adaptive neural network modeling and prediction approach on measured propagation loss data. The measured loss data were obtained using TEMS tools from two study locations in Benin City, Nigeria. Location 1 is an urban environment with mixed industrial, residential and few commercial areas. Location 2 is also an urban environment but with mixed residential and open areas. As summarized in Table 5, results show that proposed adaptive approach predicts and describes the measured propagation losses with better accuracy in terms of Standard Deviation (SD), Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) (Table 5).

Table 5: Comparison of proposed model prediction and other models with measured propagation loss data in location 1

Location	Models	MAE	RMSE	SD
1	Hata	14.10	18.60	12.04
	Log-distance	4.41	6.06	4.01
	Adaptive neural	4.10	5.02	0.40
2	Hata	16.01	17.10	6.50
	Log-distance	5.24	3.03	3.00
	Adaptive neural	2.41	1.43	1.04

CONCLUSION

Propagation models are valuable tools and algorithms for the prediction of signal propagation loss between the transmitter and receiver in locations where the wireless communication systems network is to be deployed. This research presents a detailed baseline survey of different types of propagation models and prediction techniques in cellular communication networks. Some of the key propagation models discussed include the Hata, SUI, Walfiscsh-Ikegami, Walficsh-Bertoni, Lee and ITU Models, etc. Each of the presented models has its own peculiar characteristics and limitations to use in the different radio propagation environment. This study would be of help to Radio Frequency (RF) engineers in choosing the right propagation model suitable for a given environment. This is because a hybrid neural model combining the existing models and an adaptive neural network propagation modeling capabilities will be applied to the propagation path loss prediction to address the limitations of the existing path loss models.

NOMENCLATURE AND ACRONYM

ANN = Artificial Neural Networks
h_r = Receiving tower
h_{rx} = Receiver antenna
h_t = Transmitting tower
h_{tx} = Transmitter antenna
R_x = Receiver antenna
T_x = Transmitter antenna
w_T = Weight matrix
$f_i^{[j]}$ and $O_i^{[j]}$ = the ith activation function in the jth hidden layer denoting the output from the ith neuron and the jth layer
n_1, n_2 n_3 = The small letters-Neuron number
$w^{[1]}$ $w^{[2]}$ $w^{[3]}$ = Weighted vectors
w_1 w_2, .., w_n = Neuron weight output
t = The target value
θ = Bias parameter

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