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Channel characterization and modeling for wireless communication link planning and design in the tropics

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ABSTRACT

Channel model provides basis in the link budgetary for planning and design of low margin systems of communication links. This paper proposed a simple and efficient channel model for wireless channel path loss characterization and modeling. Free space channel was characterized and modelled to account for both static and dynamic changes of signal that propagates through it. Correction factors in the model account for the losses due to refraction effects, as a result of abnormal refractivity condition frequent in tropical regions. The model was validated via measurement data from experiment conducted in a tropical region and a high level of agreement was observed. The proposed model can be deployed during link planning and budgetary for ultra high frequency (UHF) wireless radio services.

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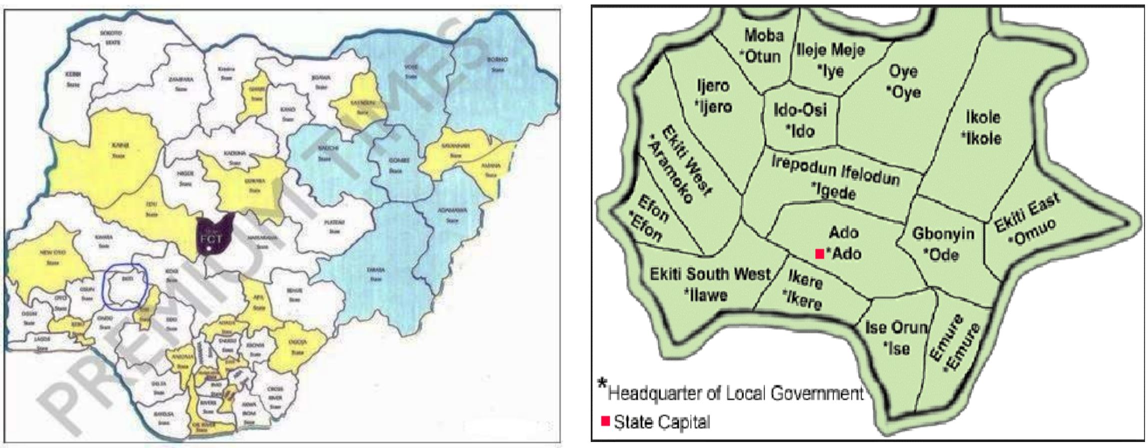
1. INTRODUCTION

Channel characterization and modeling is an indispensable task in planning and budgetary towards quality of service analysis in land mobile radio service. Propagating broadcast signal with lower frequency exhibits higher wavelength, which enhances their propagation features to be stronger, easy penetration of surfaces, and traverse longer distances without boosting the signal. For instance, ultra high frequency (UHF) bands offer the largest quantity of good quality spectrum at the best frequencies required for large professional applications. Interference in UHF bands can be easily accounted for by prediction [1]. Many authors have proposed charts, nomograms and equations/models to allow appropriate expected signal level prediction from a given transmitter at different mobile stations [2]–[11], they made it very clear that loss intensity has logarithmic characteristic against distance. In the previous works, Hata [2] reported an integrated Okumura work [3].

Okumura-Hata model is a very practical model because it's carefully arranges path loss intensity and service area. The work has been employed as a baseline data by other researchers such as [12]–[14], the signal propagation prediction methods in the report have become popular and standard for planning in nowadays land mobile systems in Japan [15]-[27]. The model is as summarized in Table 1. For better formulation, Hata [2] considered the following salient points: treated propagation loss between isotropic antennas, treated a quasi-smooth terrain, not irregular, and presented urban area propagation loss as the standard formula. A correction model to the standard was prepared for different areas. However, despite the popularity and applicability of the model, it remains complex, lacks continuity of correction factor for large city (between 200 MHz and 400 MHz), requires longer time of calculation for adequate loss predictions, and not suitable for all environment as it is site-specific. Ado-Ekiti metropolis, is in southwest of Nigeria as shown in Figure 1. Figure 1(a) shows the map of Nigeria while and Figure 1(b) shows the map of Ado-Ekiti, and the capital of Ekiti state in Nigeria with its people mainly of sub-ethnic group of Yoruba.

Table 1. Empirical propagation Loss for different area [2]

Area	Equation
Urban area	$L_p = 69.55 + 26.16logf_c - a(h_m) + [44.9 - 6.55logh_b]logd \quad (dB)$
	Correction factor for vehicular station antenna height
	Medium-Small City
	$a(h_m) = (1.1logf_c - 0.7)h_m - (1.56logf_c - 0.8)$
	Large City
	$a(h_m) = 8.29[\log(1.54h_m)]^2 - 1.1 : f_c \leq 200\ MHz$
	$= 3.2[\log(11.75h_m)]^2 - 14.97 : f_c \leq 400\ MHz$
Suburban	$L_{PS} = L_p(urban\ area) - 2\left[\log\left(\frac{f_c}{28}\right)\right]^2 - 5.4 \quad (dB)$
Open area	$L_{PS} = L_p(urban\ area) - 1.76[\log f_c]^2 - 18.33logf_c - 40.94 \quad (dB)$
	Where
	f: frequency (MHz)…..150-1500 (MHz)
	h_b: Vehicular base station effective antenna height (m)….30-200 (m)
	h_m: Vehicular mobile station antenna (m)….1-10 (m)
	d: Distance (km)…..1-20 (km)



(a) (b)

Figure 1. Map of the study area (a) map of Nigeria, blue icons showing the study area and (b) map of Ekiti State, red icons showing the study area

So far, different researchers have reported different measurement results and developed path loss models at different sites. There are empirical and/or deterministic path loss models [11]. The empirical model is measurement that depend on a particular frequency and site. They presents the relationship existing between path loss and propagation parameters, e.g. distance, frequency, and antenna heights. For instance, a log-distance model [3] employs a path loss exponent that is evaluated empirically towards the characterization of the signal intensity as distance increases. The attenuation (dB) as a result of shadow fading can be predicted via a Gaussian random variable of zero mean. Other empirical models are Egli, Longley-Rice, Hata, Okumura, and Bullington models [18]. The models are simple due to the fact that they exhibits smaller number of parameters with high accuracy level. In contrast, the parameters of empirical models are fitted from measurements. Hence, the models exhibit lower accuracy level when applied to another environment [8]. Also, empirical model represents statistical path loss for a particular distance, but could not give correct received power at a particular site.

Geographically, the town is in a valley. Most inhabitants get information or news updates from government through this broadcast television and some private companies are willing to site more television stations within the town but bad reception of broadcast signal is paramount in the area, most especially during the wet season. For this reason, it is important to determine propagation characteristics specially made for the town in order to enhance system planning for service quality evaluation in such region. The purpose of this paper is to design a simple path loss intensity prediction channel model for system design in Ado-Ekiti metropolis of Nigeria and this can be extended to other tropical regions.

The main contributions of this paper are as highlighted: i) this paper presents a detailed analysis of the previous empirical models developed for path loss prediction, such as Okumura-Hata model under different conditions; ii) broadcast signal intensity measurements were taken in a tropical region using different Ekiti State television (EKTV) broadcasting stations in Ado-Ekiti metropolis, Nigeria as a case study; and iii) the data obtained data in (i) are characterized and modeled for link planning and design. The model is validated using the measurement data.

The remaining part of the paper is sectioned as follows: section 2 gives the modeling and characterization of the wireless propagation channel proposed. Section 3 gives the simulations of the proposed model within the confine of Okumura-Hata model. Section 4 is measurements conducted for model validation, brief comments and conclusion are drawn in section 5.

2. PROPOSED MODEL

In this paper, free space medium is viewed and characterized as an open loop system exhibiting dynamic and static changes of the channel. Figure 2 shows a typical open-loop system, where *x(t)* represents the input signal, *h(t)* is the channel response, *n(t)* is the noise and *y(t)* is the output signal given as (1).

$$y(t) = h(t)x + n(t) \tag{1}$$

In wireless propagation, signal intensity is inversely proportional to a particular degree (say *m*) of distance; signal intensity at any point of observation can generally be represented as (2):

$$\frac{y(t)}{x(t)} = \frac{P\lambda}{4\pi d^m} \tag{2}$$

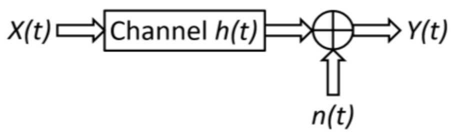


Figure 2. The system design

where λ is the signal wavelength and P denotes the constant of proportionality that defines antenna parameters: base station antenna height h_b, mobile station antenna height h_m, base station antenna gain G_b, mobile station receiver antenna gain G_m, all these parameters are constant in specific communication network systems, P is therefore (3).

$$P = h_b h_m G_b G_m \tag{3}$$

Furthermore, nature of propagation environment is another factor where the signal is diffracted, absorbed, scattered, and reflected. Refractivity is another dynamic parameter which is location dependent and function of atmospheric temperature, pressure and relative humidity. As electromagnetic wave propagates via the channel, it changes per frequency, so we therefore introduce a factor Kf^n. f is frequency, n and K parameterize the nature of the environment, which account for refractivity and multipath fading effects (such as diffraction, and reflection). Therefore (2) can be given as (4):

$$\frac{y}{x} = h = \frac{h_b h_m G_b G_m c}{4\pi\left(\frac{d}{d_0}\right)^m K\left(\frac{f}{f_0}\right)^n d_0^m f_0^n} \tag{4}$$

in practice, ideal environment does not exist, implying $n > 0$. Assuming external noise *n (t)=0,* then at an observation point, the received signal is defined as:

$$y(t) = \frac{h_b h_m G_b G_m c}{4\pi\left(\frac{d}{d_0}\right)^m K\left(\frac{f}{f_0}\right)^n d_0^m f_0^n} x(t) \tag{5}$$

$$P_r = \frac{P_t G_t G_r}{PL} \tag{6}$$

in (5) is useable for the signal intensity prediction at a particular observation point. However, loss intensity σ and the intensity of the received signal share inverse proportionality relationship (6) [2], using substitution and logarithmic method, loss intensity (path loss) gives (7):

$$\sigma(dB) = PL(d_0, f_0) + 10mlog\left(\frac{d}{d_0}\right) + 10nlog\left(\frac{f}{f_0}\right) + K \quad (7)$$

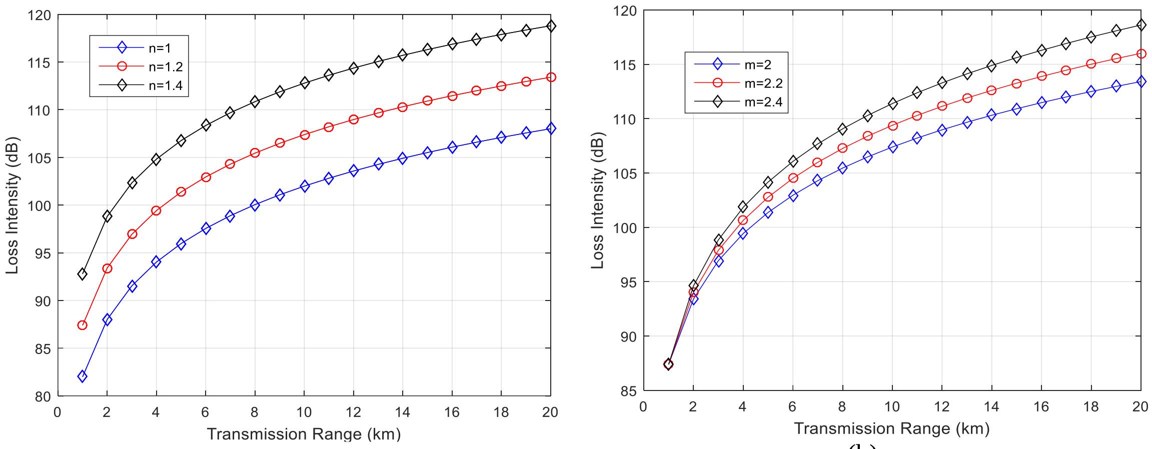
where $PL(d_0, f_0) = 10\log\left(\frac{4\pi d_0^m f_0^n}{h_b h_m c}\right)$,
frequency f is in *Hz*, the transmission distance d is in m (meter), d_0 is in meters, f_0 is in *Hz* $PL(d_0, f_0)$ is the reference path loss in *dB*, c is the velocity of propagating wave (*m/s*), K is a constant, while h_b and h_m are in *m* (meters). Exponents: *m* and *n* can be determined by parameter extraction from measurement data using (8), where *N* is the number of points, E is the expression obtained from our path loss model at different points. For instance, one data point equals the difference between the observed data and model data, carry out partial differential equation with respect to *m* and *n* and solve the consequent equations simultaneously.

$$S(n, m) = \sum_{i=1}^{N} E_i^2\,(n, m) \quad (8)$$

3. SIMULATIONS

The developed model was simulated (under Okumura-Hata model conditions) for open area, setting parameters: $h_b = 100\,m$, $h_m = 8\,m$, *f=500 MHz*, *d*=1 to 20 *km*; taking *n=1.2*, *m=2* (obeying inverse square law); assuming reference distance $d_0 = 1\,km$; reference frequency $f_0 = 1\,MHz$; consequent reference path loss $PL(d_0, f_0) = 55\,dB$; simulation results obtained are as shown in Figure 3 (Case 1: *m=2*, *n=1*, *1.2*, *1.4*; as shown in Figure 3(a), Case 2: *n=1.2*, *m=2*, *2.2*, *2.4* as shown in Figure 3(b). However, *m* and *n* are statistical values that can be obtained from measurement data. The model exhibits a high degree of conformity with various path loss models; path loss increases as transmission range increases. Correction factors, which account for refractivity and other multipath effects show great effect on the path loss intensity, an increment in them lead to higher path loss along the path of signal propagation.

The developed model was also simulated against experimental formula for propagation loss [1]. Okumura-Hata model has different parameter specifications for different propagation conditions: open area, suburban area and urban area (this includes medium-small city and large city) which characterizes different environment of propagation. The frequency discontinuity problem for large city was resolved by adding *-10 dB* to the correction factor at $f_c \geq 400\,MHz$. This experimental model was therefore used as a bench mark or standard in an attempt to validate the new model developed. Each area was simulated with frequency ranges between *10 MHz* and *30 GHz*. Correction factors parameters: *n=2.6*, *m=3.13* as extracted from the experimental data in Table 2, while parameter *K* was modeled out for each location in consideration. For $h_b = 100\,m$, $h_m = 8\,m$, *d*=1 to 20 *km* with frequencies ranges from *10 MHz* and *30 GHz*. For open area and suburban area, results obtained are as shown in Figures 4 and 5 respectively. For urban area, results obtained are as shown in Figures 6 and 7 for medium-small city and large city respectively.



(a) (b)

Figure 3. Path loss prediction against transmission distance for correction factor cases (a) for *n* and (b) for *m*

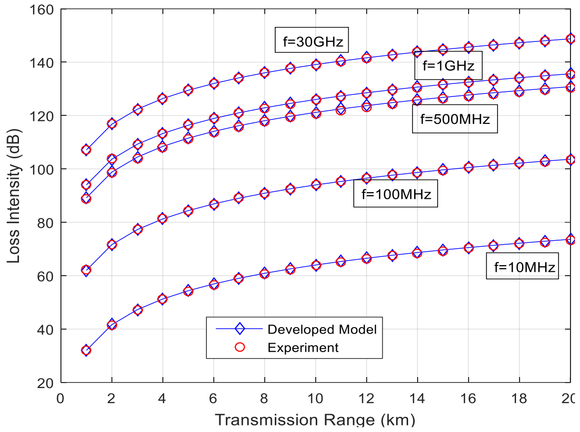


Figure 4. Path loss intensity predictions at different frequencies for open area

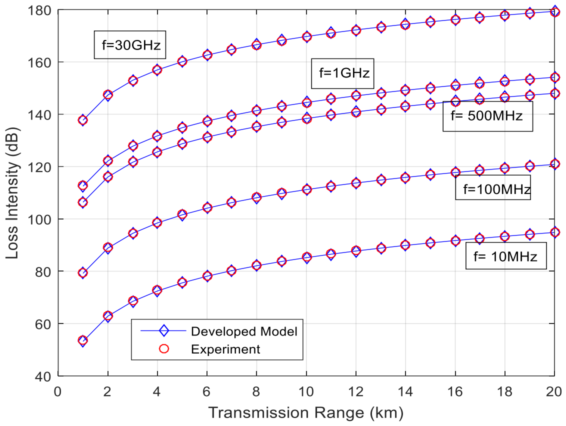


Figure 5. Path loss intensity predictions at different frequencies for suburban area

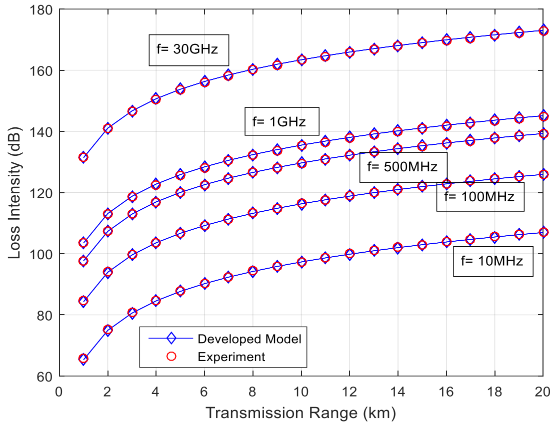


Figure 6. Path loss intensity predictions at different frequencies for medium-small city (Urban)

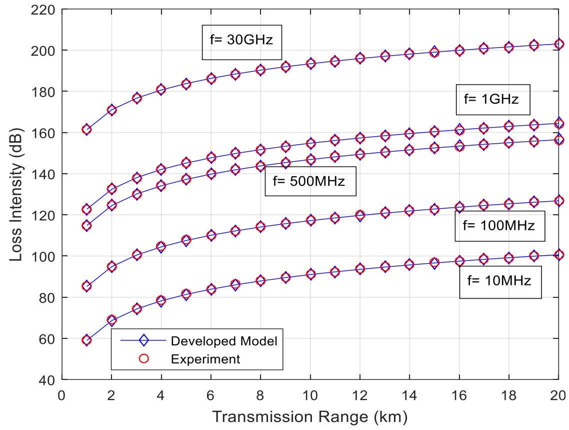


Figure 7. Path loss intensity predictions at different frequencies for large city (Urban)

Parameters: *m*, *n* determined from large city data using parameter extraction method were used for other areas (suburban, medium-small city and open area). Because other areas are function of it and they match other regions in consideration but with different *K* value and *K* strongly depending on frequency, geographical locations (multipath effects; such as reflection, diffraction) which resulted in higher path loss intensity of signal propagation. For all the areas: open area; suburban area; medium-small city; and large city, using the appropriate relationships, there is a good matching between experimental formula and developed model.

Therefore, lower frequency signals have stronger surfaces penetrability and longer distance coverage than higher frequency signals. The plot of *K* values obtained against various frequencies considered is as shown in Figure 8; all the locations gave polynomial profile relationship. At low frequencies (10-100 MHz), medium-small city overlaps suburban and large city area; this indicates a level of similarity in those environments considered during measurements campaign, but beyond 100 MHz frequencies, expected profile from those locations was achieved; indicating different propagation paths scenarios. In (8) is therefore a potential alternative to Okumura-Hata propagation model as a result of its simplicity and faster time of calculation. In (9) could be regarded as general expression for *K* factor with coefficients determinable by curve fitting (results shown in Figure 8.

Because of proper matching between measurement data and the proposed model, in (8) can therefore be applied to various environments such as open area, suburban area and urban area (medium-small city and large city) by using appropriate *K* factor where applicable. Various environments with corresponding K factor are as summarized in Table 2 where other specification parameters remain as defined for the experimental formula Table 1. Therefore (8) with different conditions summarized in Table 2 is a better replacement for the complex Okumura-Hata model summarized in Table 1. Different behavior shown in Figure 9 is due to various locations and frequencies considered, hence the proposed model is location and frequency dependent.

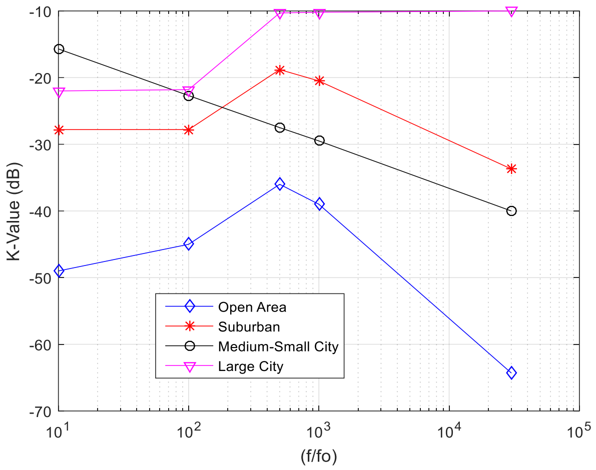


Figure 8. K-value against different frequencies considered

Table 2. K-coefficient for various areas (m=3.13, n=2.6)

Location	α_0	α_1	α_2
Open area	-73.67	28.95	-5.96
Suburban	-42.69	16.42	-3.182
Medium-small city	-8.69	-6.98	0
Large city	-33.16	10.7	-1.197

$$K = \alpha_0 + \alpha_1 \log\left(\frac{f}{f_0}\right) + \alpha_2\left(\log\left(\frac{f}{f_0}\right)\right)^2 \quad (9)$$

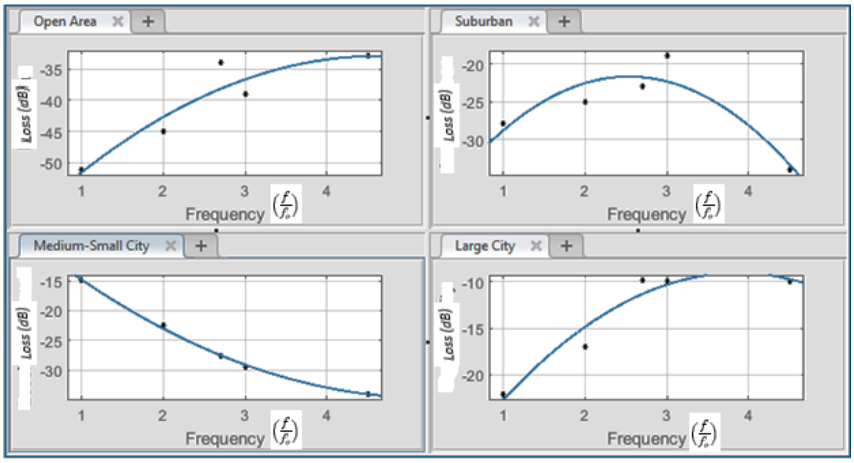


Figure 9. K-coefficients curve fitting results for all the areas considered

4. MEASUREMENT

Broadcast signal field strength measurements were carried out within Ado, Ekiti State, Nigeria. There are two television broadcasting stations in the metropolis: Nigeria Television Authority (NTA) and EKTV. However, EKTV station was selected for experiment because of access to transmitting antenna parameters/ information: Location-Ilokun, Ado-Ekiti (Longitude 07.2 °E, Latitude 10.3 °N); Channel 41 at very high frequency (VHF) band; frequency (vision) at 631.25 MHz; frequency (sound) at 617.25 MHz; polarization is horizontal; Peanut Azimuth pattern; Beam Tilt at 0.81° transmitted power of 20 kW; power gain 2.78 (3 dB); horizontal gain in main vertical lobe 30; directional gain 31.92; Transmitting Aerial is Andrews ATW series; height of the location above sea level 321 m; height of antenna 200 m. Ado Ekiti is a tropical region in southwestern part of Nigeria. The topography of Ado-Ekiti is modeled with ArcView geographic information system (GIS) and Surfer 11 software using remote sensing data. Geometric correction of the satellite image for proper location positioning which was done in remote sensing software (ArcView), the image were later interpreted before taken it to surfer, results obtained are as presented in Figure 10. Figure 10(a) presents the terrain of the study area with antenna location and measurements routes, while Figure 10(b) presents the elevation, and Figure 10(c) shows the contour of the study area.

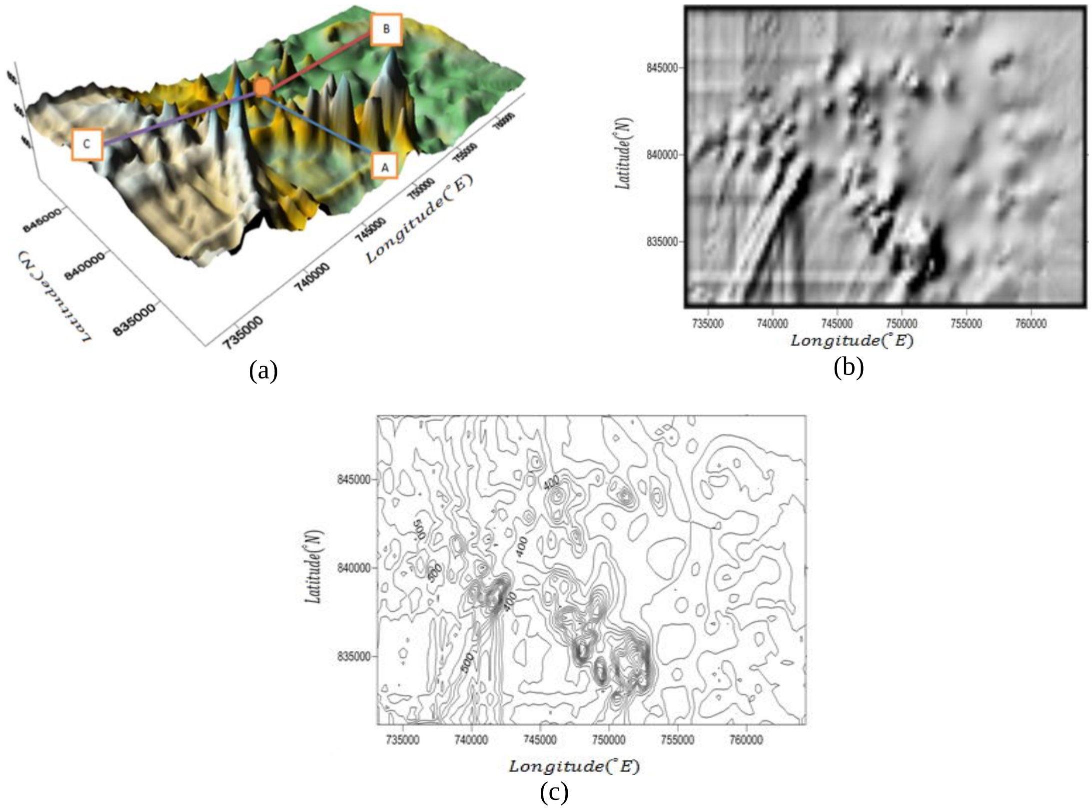


Figure 10. Topography of Ado-Ekiti (a) terrain of Ado-Ekiti with antenna location and measurements routes, (b) elevation of Ado-Ekiti, and (c) contour of Ado-Ekiti

The measurement of signal intensity was conducted around Ado-Ekiti metropolis. A Yagi antenna array in receive mode that covers UHF and VHF bands was employed. The antenna was fixed on a support of *3 m* height, in order to avoid grounding impact on the reception. The antenna is situated away from tall building and hills and the measurements were taken in the morning when the humidity is high in the atmosphere. The Yagi antenna array is connected via a 70 ohm feeder to a television field strength meter of type MS 1803, towards measuring TV signal strengths (both audio and vision) in the UHF/VHF frequency bands I, III, IV and V.

Two seasons are prominent in the region: wet and dry seasons. Measurements were taken during wet season because worse reception usually occur during the wet season. The city was divided into three major routes: route A-Afe Babalola road, route B-Akure road, route C-Iyin road for optimum coverage of the city. In (7), (10) and (11) were used to calculate the measured path loss and the result is as shown in Figure 11; curves are due to the irregular terrain nature of the city. *K* value was calculated at $m=2$ *and* $n=1$ for each point of observation and the average estimated to be *8.07 dB*, *9.16 dB,* and *4.92 dB* for routes: *A, B,* and *C* respectively. In (12)-(14) are the path loss model for each routes taken while (15) is consequently the proposed radio frequency (RF) propagation model for Ado-Ekiti metropolis, which can be extended to other tropical regions.

$$E\left(\frac{V}{m}\right) = \frac{\sqrt{30P_tG_t}}{d(LOS)} \tag{10}$$

Where P_t is the transmitted power (in *W*), G_t is the gain of the transmitter, and *d* is the LOS distance (in *m*).

$$P_r = \frac{P_tG_tG_rh_t^2h_r^2}{d^4} \tag{11}$$

where P is in watts, h_r, h_t is in metre, d_h, d are in km and f is the frequency in MHz [2].

$$\sigma(dB)_{Route\ A} = 63.07 + 20log\left(\frac{d}{d_0}\right) + 10log\left(\frac{f}{f_0}\right) \quad (12)$$

$$\sigma(dB)_{Route\ B} = 64.16 + 20log\left(\frac{d}{d_0}\right) + 10log\left(\frac{f}{f_0}\right) \quad (13)$$

$$\sigma(dB)_{Route\ C} = 59.92 + 20log\left(\frac{d}{d_0}\right) + 10log\left(\frac{f}{f_0}\right) \quad (14)$$

$$\sigma(dB)_{Ado-Ekiti} = 62.38 + 20log\left(\frac{d}{d_0}\right) + 10log\left(\frac{f}{f_0}\right) \quad (15)$$

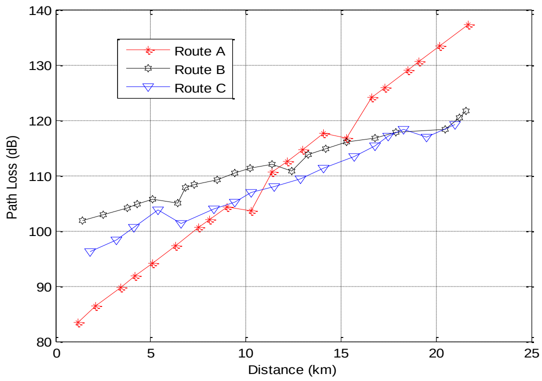


Figure 11. Path loss profile in Ado-Ekiti metropolis

5. CONCLUSION

A robust channel model has been proposed for path loss intensity prediction for adequate link budgetary and planning in wireless communication link planning. The model exhibits high level of validity with measurements campaign conducted in a tropical environment. The model is frequency and location dependent, but it is important to note its application ranges and units because it is only applicable to certain ranges. Free space channel was characterized and modelled to account for both static and dynamic changes of signal that propagates through it. Correction factors in the model account for the losses due to refraction effects, as a result of abnormal refractivity condition frequent in tropical regions. The model was validated via measurement data from experiment conducted in a tropical region and a high level of agreement was observed. The proposed model is an alternative channel characterization tool for UHF broadcast radio services in tropical areas. Detailed analysis of the previous models is also presented for adaptation in the specified area.

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