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Profiling of Radio Propagation in VHF Band

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Abstract

The Very high frequency (VHF) band spans from 30 MHz to 300 MHz and is designated for public safety and disaster relief networks, FM radio broadcasting, TV broadcasting, air traffic control and many other mission critical services. Most of these services often utilize the lower part of the VHF band and the coverage areas of such systems could be above hundreds of kilometers, which may require several transmitters operating in a quasi-synchronous mode. In addition, frequency reuse within this band for example, in the case of FM radio could result in excessive boarder area interference. Therefore, to minimize interference, even with the coexistence of these systems, there is a need to examine the behaviour of radio wave propagation in the band. Radio propagation models have been used extensively in interference analysis, coverage prediction and optimization. Most of the widely used models are location dependent, which, therefore, calls for continued efforts to ensure that location specific measurements are taken and used as planning tools, towards understanding the limitations arising from specific environmental conditions. In this work, Electromagnetic field (EM) strength measurements were conducted in Ilorin (Long 4^o 36’ 25”E, Lat 8^o 25’ 55’’N) and its environs within Kwara State, Nigeria, along some predefined routes, using dedicated Agilent N943C 100 Hz - 7 GHz spectrum analyzer. For each route, the measured received signal levels (RSLs) were obtained, profiled over the terrain and compared with simulated signal values obtained for COST 231, Egli, Hata and ILORIN models. A total of three transmitters were utilized; two in the lower VHF (LVHF) and one in the upper VHF (UVHF) bands. Results obtained showed that there is severe fading along all the routes considered, for all the broadcasting stations, with the highest signal level estimation observed for Egli, followed by COST 231, Hata and ILORIN model in that order. Measurements results also indicate that the received signal level is found to follow the terrain elevation for the models considered. However, the ILORIN model, which is a localized model was found to provide better predictions, despite the fact that the signal follows the terrain profile.

Keywords: Received Signal, VHF, Terrain, Electromagnetic Waves

1. Introduction

The wireless medium is becoming an unavoidable ingredient of life, as a means of information transmission. This is because of the continuing emergence of wireless devices applicable in critical areas of life, like the public safety, security, commerce, transportation, health care delivery etc. It behooves us, to ensure that service delivery, particularly public safety communication through this medium is satisfactorily proficient.

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The VHF band span from 30 MHz to 300 MHz and is designated for public safety and disaster relief networks, FM radio broadcasting, TV broadcasting, air traffic control, space exploration and many other services. Table 1 provides an overview of Nigeria's VHF frequency allocation. Most of these systems often utilize the lower part of the VHF band which spans from 49-108 MHz and the coverage areas of such systems could be above hundreds of kilometers which may require several transmitters operating in a quasi-synchronous mode.

TABLE 1: National VHF band allocation

FREQUENCY BANDS (MHz	ALLOCATIONS	UTILIZATION	REMARKS
30 - -47	Space Operation, Fixed Mobile Radio Astronomy	ISM	This band is empty except 40.660-40.700 MHz which is designated for ISM. There is no protection of other services.
47 – 68	Broadcasting Land Mobile	Land Mobile	Cordless systems
68– 87.5	Fixed Mobile except aeronautical mobile,	Fixed Mobile except aeronautical mobile	Cordless systems, 74.8 - 75.2 MHz is empty
87.5-108	Broadcasting	FM radio broadcasting	States licenses are issued on this band by frequency reuse. Boarder areas interference may exist.
108-146	Aeronautical Radio navigation, Aeronautical Mobile (R), Space Operation Meteorological satellite	Aeronautical Radio navigation, Aeronautical Mobile (R)	VOR/ILS localizer, VHF voice/data communication (air-ground and air-air) EPIRB on 121.5MHz, Low earth orbiting satellites only 137- 138. 137-146 has not be used
146-174	Fixed Mobile Except Aeronautical Mobile (R),	Fixed Mobile Except Aeronautical Mobile (R), Maritime Mobile (Distress and Calling via DSC)	Two- way radio (PMR) or public safety networks, Short range voice comm. (ship-ship, ship-shore, shoreship)
174- 230	Broadcasting	TV Broadcasting	State TV licenses broadcasting on VHF. These stations are commonly known as NTA.
230-300	Fixed Mobile, Aeronautical Radio navigation	Fixed Mobile	

Within the lower VHF (LVHF) as shown in Table 1, most of the frequencies between 30 MHz- 68 MHz, which are primarily allocated for space operation and other cordless land mobile services, are not utilized except for 40.660-40.700 MHz which is designated for ISM. There is no protection of other services in this band. The frequencies from 87.5-108 MHz within the LVHF are heavily utilized by FM radio broadcasting stations and states' FM radio licenses are issued on this band and are assigned center frequencies at 200 kHz with a maximum of 100 FM stations. Due to the geographical area of the country and demand for FM stations within each state, frequency reuse is the method used by the regulators for frequency allocation and these could amount to excessive border area interferences. The upper VHF (UVHF) band spans from 169-300 MHz and these are mainly licensed to TV broadcasting stations and fixed mobile network.

Other mission critical services on this band include: Directional Radio Range (VOR), instrument landing system (ILS) and public safety networks. The VOR enables the aircraft to determine its position and stay on course, by receiving radio signals transmitted by a fixed ground radio beacon (Kayton, 1997) while the ILS allows aircraft to land in a situation where the pilot is unable to establish visual contact with the runway (Crane, 2012). Public Safety and disaster relief networks are 24-hour communications facilities, which respond to fire, natural and artificial disasters, medical emergencies, threats to public order and a host of other life-threatening situations (Arthur, 2012). Public Safety (PS) Organizations play critical roles in disaster preparedness and recovery, assisting in the response to emergency events, including catastrophic disasters.

In Nigeria, public safety communication infrastructure have not been given attention, as most of the public safety organizations (i.e. National Emergency Management Agency (NEMA) and federal road safety corps (FRSC), police, fire departments and Emergency Medical Services (EMS) use the traditional cellular system as a means of communications and these networks are prone to network congestion, interoperability problems all of which make it very difficult for first responders, from different agencies and locations, to communicate and coordinate.

In order to minimize interference and aid coexistence of these systems operating on the VHF bands, there is need to examine the behaviour of radio wave propagation in that band. Radio propagation models have been used extensively in interference analysis, coverage prediction and optimization. Researchers have formulated prediction models, some of them, analytical while some are empirical. Results outcomes from Faruk *et al.* (2013)a, Faruk *et al.* (2013)b, Phillips *et al.* (2011), Phillips *et al.* (2012), Obiyemi *et al.* (2012) and many others have however shown that empirical models which are environment-dependent do much better than the analytical ones, in the case of field strength prediction. This is as a result of dependence of radio propagation on the nature and form of environment, such as size, arrangement of buildup areas, vegetations and topography).

Therefore, the aim of this work is to profile radio propagation in VHF bands and also to verify the fitness of one of the widely used empirical path loss models, in predicting electromagnetic field strengths in the VHF bands in Ilorin.

2. Related Works

Several measurement campaigns have been carried out to examine the behaviour of radio wave propagations, one of which is the work by Akinwole and Biebuma (2013), who conducted a drive test in Rivers State, Nigeria. The measurement was conducted in nine different locations, in the rural, suburban and urban areas. Three propagation models, COST 231 Hata, SUI and ECC-33 models were compared at a frequency of 2100 MHz, with COST 231 Hata model found to provide better performance. Dajab and Ogundapo (2008) used two empirical path loss models, COST-231 Hata and LEE models and one semi-empirical path loss model, COST-231 Walfisch-Ikegami model to analyze data collected from nine different base stations in Kano State, Nigeria, for GSM macro cells at 900 MHz.

Popoola and Oseni (2014) took measurements from two GSM 900 MHz and 1800 MHz base stations sites in Makurdi, Benue State, and they concluded that, Standard Propagation and COST 231 models are the most suitable at the two frequencies, for deployment of GSM, in the study area. Deme *et al.* (2013) conducted measurements in Borno State, using seven base stations of mobile telecommunications network (MTN) provider, within Maiduguri at 900 MHz. Omorogiuwa and Edeko (2009), conducted measurements at 900/1800 MHz bands, within three mountainous environments in Igarra (Edo state), Ajaokuta and Okene (in Kogi State), Nigeria. Obot *et al.* (2011) found that the Hata model provided the lowest mean square error (MSE) value of 2.37 dB at 870.52 MHz, in Akwa-Ibom State of Nigeria. Similarly, Isabona and Isaiah (2013) conducted measurements in Port-Harcourt, capital of Rivers state, Benin capital of Edo state and Uyo capital of Akwa-Ibom state all in Nigeria to compare the performances of seven different propagation models. The work concluded that the Walficsh Bertoni model provides the best fit.

Surajudeen-Bakinde *et al.* (2012) took measurements from some routes from Kano State and Abuja Federal Capital Territory of Nigeria to predict the most fit propagation models for GSM 1800 and WCDMA. It was concluded in the work that Hata and COST 231 gave fairer results for the two urban areas considered. In another work, Ayeni *et al.* (2012) compared different models using measurements data taken from Kano State of Nigeria. Away from Nigeria, researches are still on going on path loss models for GSM all over the world. Rakesh and Srivatsa (2013) took measurements at 940 MHz in India, (Ali, 2014) in Ukraine and many other works presented, globally, such as: (Ekpenyong *et al.,* 2012; Akinwole and Biebuma, 2013; Kwakkemaat and Herben, 2011; Iskander and Yun, 2012; Kwak *et al.,* 2006; Faruk et al., 2013c; Phillips *et al.,* 2011; Phillips *et al.,* 2012; Obiyemi *et al.,* 2012; Faruk *et al.,* 2013d; Jimoh *et al.,* 2015 and Hata, 1980) who have also done extensive works on the prediction of propagation models for wireless communication systems.

Although, lots of measurement campaigns have been conducted and reported in various locations, most of these works concentrate on the cellular bands, usually frequencies above 800 MHz, driven by the commercial interest of the mobile network operators, while only a few have worked on the TV bands. The few published works on the TV bands did not consider the VHF bands as more efforts are devoted to the UHF bands. These limit the number of available empirical data and validated prediction methods in the VHF bands indicating what type of signal degradation and fading one should expect in various urban environments. Moreover, numerous emergency networks, such as radionavigation, military communications systems operate in the VHF band; these necessitate the need to examine the behavior of radio propagation in this band.

3. Method of Data Collection

The propagation measurements were conducted in Ilorin (Long 4° 36’ 25”E, Lat 8° 25’ 55’’N) and its environs within Kwara State, Nigeria. Ilorin is a large city characterized by a complex terrain due to the presence of hills and valleys within the metropolis. Seven routes (Routes 1-7), which are Route 1 Unilorin- Tanke - Fate- Basin; Route 2 Basin- Sango-KWTV; Route 3 KWTV- Unilorin Teaching Hospital- Oke Oyi; Route 4 University Teaching Hospital- Maraba- Ipata-Oja oba; Route 5 Oja Oba- Oja Iya- along Taiwo; Route 6 Oja Oba- Agaka – Garin Alimi-Asadam- NTA Ganmo, and Route 7 NTA-Ganmo-ARMTI, as shown in Fig 1, were covered during the measurement campaign with Table 3 giving the transmitters details. For each route, the prediction error for COST 231, Egli, HATA and ILORIN models was obtained and profiled over the terrain for some selected routes. The prediction error is the difference between the measured path loss at given distance *i*, and the model's predicted path loss. HATA (1980) model for large city was used. A total of three transmitters were utilized, that is, NTA, UNILORIN and Harmony, transmitters operating at 203.25 MHz, 89.3 MHz and 103.5 MHz frequencies respectively. While the transmission is going on, a dedicated Agilent N9342C 100 Hz-7 GHz spectrum analyzer having a GPS (Global Positioning System) device was placed inside a vehicle with the GPS device attached to the roof of the vehicle, driven at an average speed of 40 km/h along these routes, during broadcast. Field strengths were measured, continuously, and stored in an external drive for subsequent analysis. Table 2 presents the equipment configuration details.

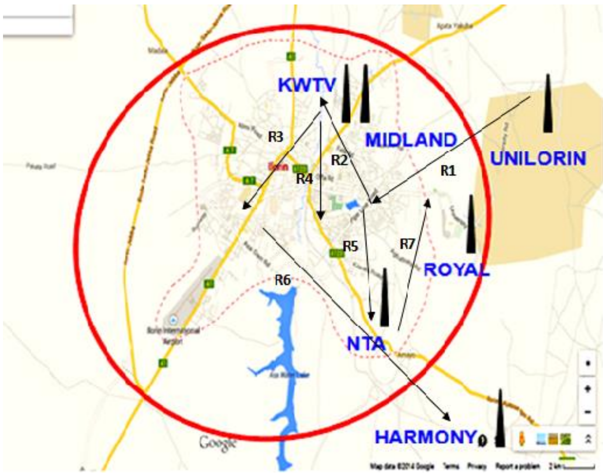


Figure 1: Measurement Routes and Scope

Figure 2: Measurement Experiment Set-Up

TABLE 2: Measurement equipment and configuration during validation

Spectrum Analyzer N9342C Agilent, 100 Hz- 7 GHz	
Displayed average noise level (DANL)	-164 dBm/Hz
Preamplifier	20 dB
Resolution bandwidth (RBW)	10 kHz
Impedance	50 Ω
Centre frequency (NTA) Centre frequency (UNILORIN) Centre frequency (HARMONY FM)	203.25 MHz 89.30 MHz 103.5 MHz
Receiver Antenna: Diamond RH 795	
Frequency range	70 MHz-1 GHz
Form	Omni directional
Height	1.5 m
Gain	2.51 dBi

TABLE 3: Transmitters' Parameters

S/No	Transmitter	Antenna Height (m)	Operating Frequency (MHz)	Transmit Power (kW)	Longitude	Latitude
1	Unilorin FM	100.0	89.30	1.0	4°40' 28"E	8°29' 21"N
2	Harmony FM	125.0	103.50	7.0	4º 36' 25"E	8º 25' 55''N
3	NTA	185.0	203.25	2.6	4º 36' 25"E	8º 25' 55''N

4. Radio Propagation Prediction Models

In this paper, three widely used empirical path loss models are considered alongside a localized path loss model built, based on local electromagnetic field strength measurements, conducted in Ilorin. The chosen models are Hata (1980), COST 231 (1991), Egli (1957) and ILORIN model in Faruk *et al.* (2014). This paper therefore intends to profile the radio wave propagation in the VHF bands to see if these widely models could be used to estimate signal level in Ilorin environment.

A. HATA MODEL

Hata (1980) provides a mathematical equation of the graphical path loss data provided by Okumura (1968). The frequency validity range for this model 150 MHz to 1500 MHz for transmission distance up to 20 km. Hata model has been deployed world-wide for predicting analogue TV signal propagation. In order to improve on the accuracy in signal prediction in different areas, Hata provides a set of correction factors which account for urban, sub-urban and open environmental scenarios. The propagation formulas are as follows:

(a) For urban areas

$$L_{Hata} = 69.55 + 26.16 \times \log f_c - 13.82 \times \log h_t - a(h_r) + (44.9 - 6.55 \log h_t) \times \log d \quad (1)$$

where L is the path loss (in dB), f_c is the operating frequency (in MHz), h_t the transmitter height (in meters), h_r receiver height (in meters), d distance between the transmitter and the receiver (in km) and $a(h_r)$ is the correction factor for the receiver height. The model is restricted to: f_c: 150-1500 MHz, h_t: 30-200 m, h_r:1-10 m, d: 1-20 km. The correction factor $a(h_r)$ is computed as follows:

i. For a small and medium city

$$a(h_r) = (1.1 \times \log f_c - 0.7)h_r - (1.56 \times \log f_c - 0.8)\,\text{dB} \quad (2)$$

ii. For a large city

$$a(h_r) = \begin{cases} 8.29 \times (\log 1.54 h_r)^2 - 1.1, & f \leq 200\,\text{MHz} \\ 3.2 \times (\log 11.75 h_r)^2 - 4.97, & f \geq 400\,\text{MHz} \end{cases} \quad (3)$$

(b). For sub-urban areas

$$L(dB) = L(urban) - 2 \times [\log(f_c/28]^2 - 5.4 \quad (4)$$

(c). For open areas

$$L(dB) = L(urban) - 4.78 \times (\log f_c)^2 + 18.33 \times \log f_c - 40.94 \quad (5)$$

B. COST 231 Model

Hata's model restriction for frequency of 1500 MHz necessitates the development of COST 231 model. COST 231 model was developed by Co-operative for Scientific and Technical Research technical committee (Rappaport, 1999). This model was developed as an extended version of the Hata model such that applicability up to 2 GHz is possible and therefore, applications like GSM in the 1800 MHz band and other similar systems operating between 1800 and 1900 MHz would be possible. COST 231 model is given in COST 231 (1991) as:

$$L = 46.3 + 33.9 \times \log f_c - 13.82 \times \log h_t - a(h_r) + (44.9 - 6.55 \log h_t) \times \log d + C_m \quad (6)$$

C_m =0 dB for medium-sized city and suburban areas and 3 dB for metropolitan centres. a(h_r) is as defined in (2), and h_t, h_r and d are valid for the same ranges as in (1). This model could be used to predict TV signal propagation.

C. Egli Model

Egli (1957) performed series of measurements between 90 MHz and 1000 MHz over irregular terrain. It was concluded that the median signal level in a small area follows the inverse–fourth-power law. This attribute is similar to the plane earth propagation model but with an excess loss over the plane earth model. Egli model does not provide any validity range for the distance; however, TV band falls within the frequency range. Egli path loss is given as follows:

$$L(dB) = 20 \times \log f_c + 40 \times \log d - 20 \times \log h_T - 10 \times \log h_r + 76.3 \quad \text{For } h_r \leq 10 \quad (7)$$

$$L(dB) = 20 \times \log f_c + 40 \times \log d - 20 \times \log h_T - 10 \times \log h_r + 85.9 \quad \text{For } h_r \geq 10 \quad (8)$$

D. ILORIN Model

The ILORIN model (Faruk *et al.*, 2014) is an optimized Hata-Davidson empirical model (Davidson, 1997) the model has been found to best fit in path loss signal prediction in the VHF and UHF bands in Ilorin Kwara State of Nigeria, following the work presented in Faruk *et al.* (2013)a and Faruk *et al.* (2013)b. ILORIN model is defined as follows:

$$L_{opt}(\text{dB}) = 73.56 + 26.16 \times \log f_c - 13.82 \times \log h_t - a(h_r) + 30.5 \times \log d + A(h_T, d_{km}) - S_1(d_{km}) - S_2(h_T, d_{km}) - S_3(f_{MHz}) - S_4(f_{MHz}, d_{km}) \quad (9)$$

where C represents the correction factors $A(h_T, d_{km})$, $S_1(d_{km})$, $S_2(h_{T,} d_{km})$, $S_3(f_{MHz})$ and $S_4(f_{MHz}, d_{km})$ as defined in the Hata-Davidson model and a(hr) is defined in (2)

$$PL_D = L_{HATA}(dB) + A(h_{te}, d_{km}) - S_1(d_{km}) - S_2(h_{te}, d_{km}) - S_3(f_{MH_z}) - S_4(f_{MH_z}, d_{km}) \quad (10)$$

where

$$A(h_{te}, d_{km}) = \begin{cases} 0 & ; \quad d < 20\,km \\ 0.62317*(d-20)[0.5 + 0.15*\log(h_{te}/121.92)]; & 20\,km \le d < 64.38\,km \\ 0.62317*(d-20)[0.5 + 0.15*\log(h_{te}/121.92)]; & 20\,km \le d < 300\,km \end{cases}$$

$$S_1(d_{km}) = \begin{cases} 0 & ; \; d < 20km \\ 0 & ; \; 20\,km \le d < 64.38\,km \\ 0.174(d - 64.38); & 64.38\,km \le d < 300\,km \end{cases}$$

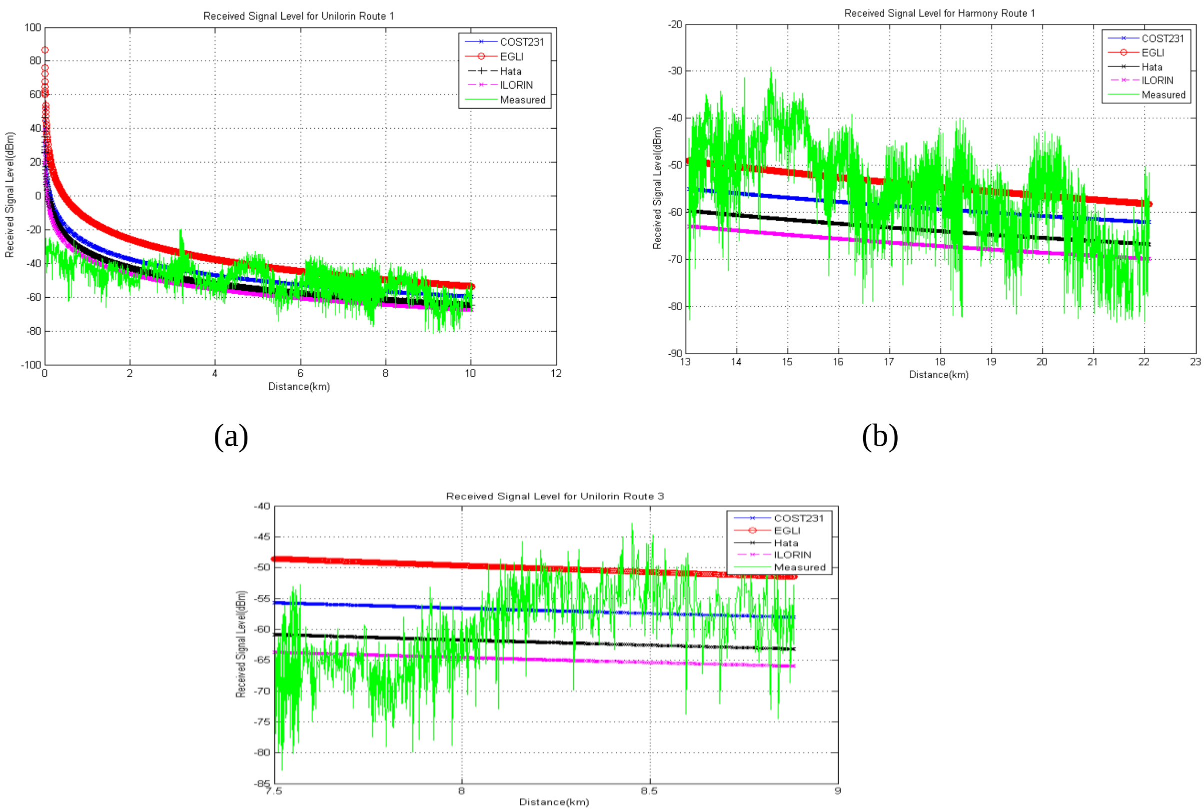
$$S_2(h_{te}, d_{km}) = 0.00174484|\log(9.98/d)|(h_{te} - 300) \qquad \text{if} \quad h_T < 300m$$

$$S_3(f_{MH_z}) = f \big/ 250 \times \log(1500/f)$$

Results and Discussion

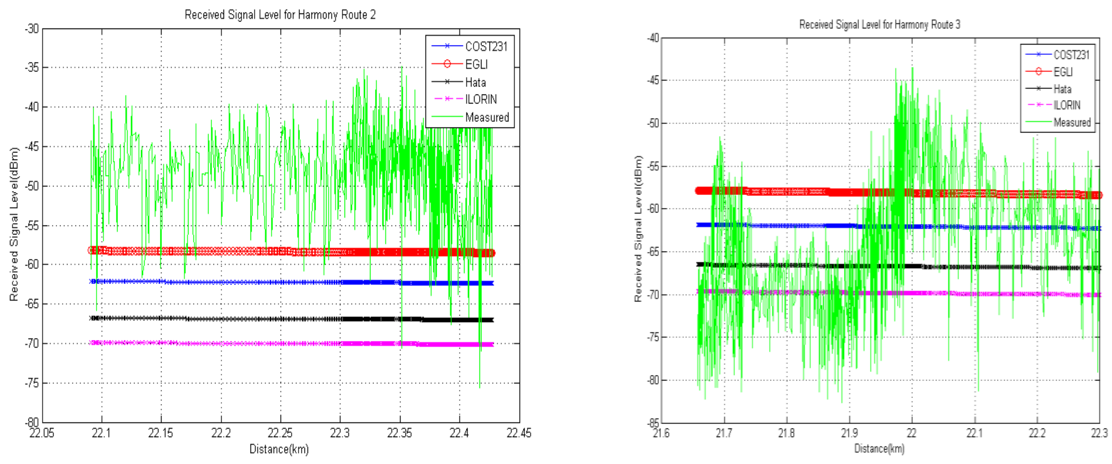
The graphical representations of the measurements taken, on Unilorin, Harmony and NTA, transmitters are presented in Figures 3a, b and c respectively. It can be seen from Figure 3a, that Egli, overestimated for most part, up to about 3 km, while all others performed reasonably well, all through the measurement routes. It is noteworthy that COST 231 performed, most brilliantly, after 6 km. The ILORIN model, in the mean, performed very well all through. The four models under study performed fairly well except that the ILORIN model underestimate for most parts of the route. In Figure 1c, Egli overestimated for most parts of the route, COST 231 is found to do, a fairly good, mean estimation while, ILORIN underestimated at the latter part of the route. Hata performed best within this segment of the route.

Figures 4 (a)-(b) show the graphical representation of received signal with distance of the Harmony transmitter routes 2 and 3 as a function of terrain elevation respectively. In Figure 4 (a) all the four models, considered, including Egli, are found to underestimate, the received signal level. In Figure 4 (b) Egli performed poorly, overestimating, earlier on the route, ILORIN performed, poorly, underestimating at the latter part of the route. Hata, did, fairly well, with COST 231 overestimating, at the lower part of the route while doing better, at the latter part.



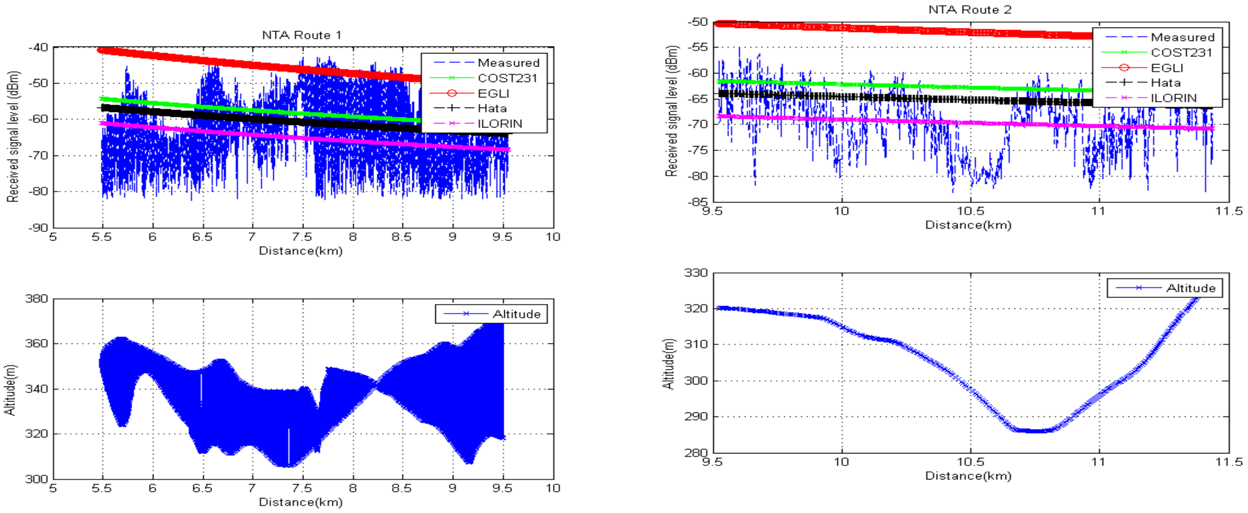
(c)

Figure 3: Received signal per distance of the (a) Unilorin transmitter route 1 (b) Harmony transmitter route 1 (c) Unilorin route 3

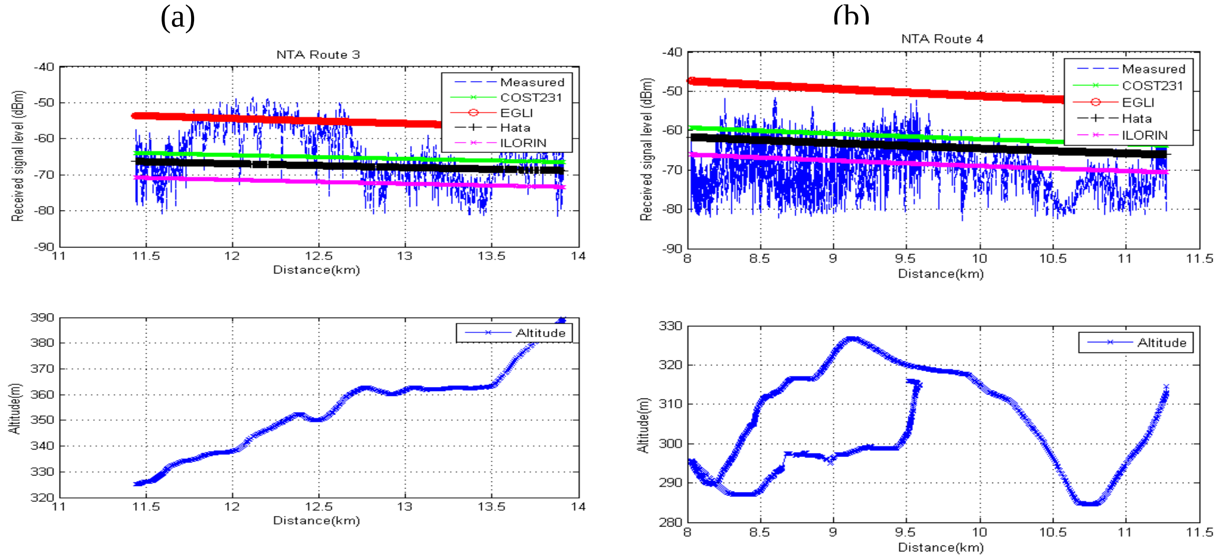


(a)   (b)

Figures 4: Received signal per distance of the Harmony transmitter (a) route 2 (b) route (3)



(a)   (b)



(c)   (d)

Figure 5: NTA transmitter as a function of terrain elevation (a) route 1 (b) route 2 (c) route 3 and (d) route 4.

Figures 5 (a)-(d) provide results for field strength as a function of distance and terrain elevation for NTA transmitter along route 1, route 2, route 3 and route 4. In Figure 5 (a), Egli performance was very poor, while COST 231 was fair with Hata and ILORIN performance being good. The unusually high received signal level, around kilometer 10.75, a valley is consequent upon an LOS view of the NTA transmitter. In Figure 5 (b) Egli overestimated, for most part of the route, ILORIN underestimated, for most of the route while COST 231 and Hata performed fairly well. In Figure 5 (c) Egli performed, poorly, all through, COST 231 performed poorly, for most parts of the route, while Hata and ILORIN did, fairly well, with ILORIN performing best.

5. Conclusion

In this work, radio wave was profiled in the VHF band over Ilorin. Severe fading of signals all through the routes for all the stations was observed. Estimation of signal level is highest with Egli, followed by, COST 231, Hata and ILORIN, in that order. It was observed that terrain and frequency have significant impacts on the prediction models. Measurements results also indicate that the received signal level is found to follow the terrain elevation for the models considered. However, ILORIN model which is a localized model was found to provide better predictions despite the fact that the signal follows the terrain profile.

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