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Path Loss and Path Loss Exponent Estimation for Television Services Over Osun State Region

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Abstract

Television stations have faced a major challenge of poor signal strength, path loss and path loss exponent over the years. This is due to the reduction of power density of the electromagnetic wave as it passes through a multipath propagation environment. Path loss describe the signal attenuation characteristics between a transmitting and a receiving antenna as a function of the propagation distance and other parameters and are extensively used for conducting feasibility studies i.e. signal prediction, coverage optimization etc. Some of the important parameters used for quantifying path loss include the transmitter power, antenna height, the distance between the transmitter and the receiver and other salient details about notable obstacles in the signal path, such as tall buildings, vegetation etc.Drive test measurements was conducted on transmitted signals for all the broadcast television transmitters in Osun state. The measurement was based on routes defined by access roads, while the received field strength is taken at intervals of 3Km away from the transmitting site. Out of the lot of the different path loss models available for analysis, only a few would be looked into, which are; COST-231 Hata model, Egli model, Free space model, Okumura Hata model, Ericsson model and Lee model. The models are suitable for comparison because they fall under the transmitting frequency range of the base stations considered for the analysis. Also, path loss exponent was estimated by using the Log-distance model.

Keywords: Path loss, path loss exponent, signal strength, attenuation, model.

1.0 Introduction

Path loss exponent can be estimated from field strength.The signal strength also depends on whether the locality is rural, industrial or urban. The coverage areas of broadcast stations are usually classified into primary, secondary and fringe areas. Apart from weather conditions; the size of each of these areas also depends on the transmitter power, the directivity of the aerial, the ground conductivity and the frequency of propagation. The coverage area decreases with increase in frequency and reduction in the ground conductivity[1].

The primary coverage area is a region about a transmitting station in which the signal strength is adequate to override ordinary interference in the locality at all times, and corresponds to areas in which the signal strength is at least 60 dBμV[2].

The secondary coverage area is a region where the signal strength is often sufficient to be useful but is insufficient to overcome interference completely at all times. The service provided in this area may be adequate in rural areas where the noise level is low. The secondary coverage area corresponds to the area in which the signal strength is at least 30 dBμV, but less than 60 dBμV[2].

The fringe service area is that in which the signal strength can be useful for some periods, but its service can neither be guaranteed nor protected against interference. This is an area in which the signal strength is greater than 0 dBμV, but less than 30 dBμV[2].

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All electromagnetic waves obey the inverse-square law in free space. The inverse-square law states that the power density of an electromagnetic wave is proportional to the inverse of the square of the distance from the source. That is, if the distance from a transmitter is doubled, the power density of the radiated wave at the new location is reduced to one-quarter of its previous value. Also, the electromagnetic waves coming from a transmitter may experience three other phenomena: reflection, diffraction, and scattering. All of these factors affect the transmitted signal as it is "carried" through the air medium to the distant receiving antenna[2].

Computation of path loss is an essential element of the system design in any communication system. In radio and in TV broadcast system, estimation of the path loss is very significant as environment is continuously[3] changing with respect to time.

Then question arises how to compute the path loss with utmost accuracy. Then the answer is by using the concept of propagation model. In the latest years, propagation models have been emerges as an active area of the study. A reliable propagation model is the one which estimate the path loss with the highest accuracy and with small standard deviation[7].

An ideal propagation means equal propagation in equal directions. Unfortunately, in real situation it is not feasible due to some factors between the base station (BS) and the mobile unit (MU) that attenuates the signal, such factors may be responsible for reflecting, refracting, absorbing, and scattering the GSM signal before reaching the MU.

2.0 Computational Methods

Empirical models were used for the computation of the path loss and the path loss exponent. These models use all the parameters like the received signal strength, frequency, antenna heights and terrain profiles which were derived from a particular environment by the use of extensive measurements and statistical analysis as well. These models can then be used to design the systems which operate on similar environmental condition as the original measurements [4].

2.1 The Clutter Factor Model

Measurements taken in urban and suburban areas usually find a path loss exponent close to equation (1), same as in the plane earth loss but with a greater absolute loss value. This led to some models being proposed which consist of the plane earth loss plus an extra loss component called the clutter factor. The various models differ basically in the values, which they assign to k and n for different frequencies and environments. An example of clutter factor model is the method due to Egli, which is based upon a large number of measurements taken around American cities. The total loss defined by this model is shown in the following mathematical representations.

$$L_m = 40\log(hm) + L \qquad (1)$$

where,

$$L_m = 76.3 - 10\log(hm) \quad \text{for } hm < 10 \qquad (2)$$

and,

$$L_m = 76.3 - 20\log(hm) \quad \text{for } hm > 10 \qquad (3)$$

where *Lm* is the measured path loss, *L* is the experimental path loss and *hm* is the height of the receiving height.

2.2 Log Distance Path Loss Model

Both theoretical and measurement-based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels. The average large-scale path loss for an arbitrary T-R separation is expressed as a function of distance by using a path loss exponent, n

$$\hat{P}_L(d) \alpha \left(\frac{d}{d_o}\right)^n \qquad (4)$$

or,

$$\hat{P}_L(dB) = \hat{P}_L(d_o) + 10n\log\left(\frac{d}{d_o}\right) \qquad (5)$$

where n is the path loss exponent, which indicates the rate at which the path loss increases with distance,

d_0 is the close-in reference distance which is determined from measurement close to the transmitter, and d is the T-R separation distance.

The bars in equations (4) and (5) denote the ensemble average of all possible path loss values for a given value of d.

$$n = \frac{P_r\left(d_{\min}\right) - P_r\left(d_{\max}\right)}{10 \times \left\{ \log_{10}\left(\frac{d_{\max}}{d_o}\right) - \log_{10}\left(\frac{d_{\min}}{d_o}\right) \right\}} \qquad (6)$$

When plotted on a log-log scale, the modelled path loss is a straight line with a slope equal to 10n dB per decade. The value of n depends on the specific propagation environment. For example, in free space, n is equal to 2, and when obstructions are present, n will have a larger value.

2.3 The Okumura-Hata Model

This is a fully empirical prediction method, based upon an extensive series of measurements made in and around Tokyo city between 200MHz and 3GHz. The method involves dividing the prediction area into a series of clutter and terrain categories, namely open, suburban and urban.

Okumura's prediction of median path loss is usually calculated using Hata's approximation as follows :

Urban areas; $L(dB) = A + B\log R - E$ (7)

Sub urban areas; $L(dB) = A + B\log R - C$ (8)

Open areas; $L(dB) = A + B\log R - D$ (9)

where,

$$A = 69.5 + 26.16\log fc - 13.82\log hb \qquad (10)$$

$$B = 44.9 - 6.55\log hb \qquad (11)$$

$$C = 2\left(\log\left(\frac{fc}{28}\right)\right)2 + 5.4 \qquad (12)$$

$$D = 4.78(\log fc) + 18.33\log fc + 40.94 \qquad (13)$$

$E = 3.2(\log(11.75hm))2 - 4.97$ fc ≥ 300MHz for large cities (14)

$E = 8.29(\log(1.54hm))2 - 1.1$ fc < 300 MHz for large cities (15)

$E = (1.1\log fc - 0.7)hm - (1.56\log fc - 0.8)$ for medium to small cities (16)

where hm is the height of the receiving antenna, hb is the height of the transmitting antenna, fc is the transmission frequency, R is the radial distance away from the transmitter and L is the path loss.

2.4 Cost- 231 Hata Model

Hata-Okumura model developed by Hata is extended as Cost-231 Hata model. Cost- 231 Hata model is given as,

$$PL(dB) = 46.3 + 33.9\log_{10}(f) - 13.2\log_{10}(\log_{10}(hb)) - a\,h_m + (44.9 - 6.55(\log_{10}(hb)))\log_{10}(d) + c_m \qquad (17)$$

where f is the frequency in MHz, d *is* the distance between the base station and mobile station in Km, h b is the antenna height of the base station in meters. The correction parameter ah_m is defined for urban and suburban environments as per (18) and (19).

$$a\,h_m = 3.2\left(\log_{10}\left(11.75\,h_r\right)\right)^2 - 4.97 \qquad (18)$$

$$a\,h_m = \left(1.11\log_{10}(f) - 0.7\right)h_r - \left(1.56\log_{10}(f) - 0.8\right) \qquad (19)$$

where h_r is the height of the mobile station antenna in metre.

The correction parameter $c_m$is given as $c_{m(urban)}$ = 3db and $c_{m(suburban)}$ = 0 db.

$$n_{\cos t} - 231_{Hata} = \frac{\left(44.9 - 6.55\log_{10}\left(h_b\right)\right)}{10} \qquad (20)$$

The theoretical path loss exponent for Cost-231 Hata model is given in (20). In this paper the feasibility of Cost-231 Hata model is checked for 900 MHz frequency band, for the suburban region, with receiving antenna height of 1.5 meters.

2.5 The Lee Model

This is a power law model with parameters taken from measurements in a number of locations, together with a procedure for calculating an effective base station antenna height which takes account of the variations in terrain. It can be expressed in the simplified form:

$$L = 10n\log R - 20\log h_{b_{eff}} - P_o - 10\log hm + 29 \qquad (21)$$

where n and P_0 are given by measurements, L is path loss, hm is the height of the receiving antenna and hb_{eff} is the effective base station antenna height.

2.6 Stanford University Interim Path Loss Model

Stanford University Interim (SUI) channel model is developed for IEEE 802.16 broadband wireless access working group based on research results of Stanford University. This model covers three common terrain categories. Category A is the maximum path-loss category, which represents a hilly terrain with moderate to

heavy tree densities. Category B is the intermediate path-loss category suitable for flat terrains. The minimum path-loss category for flat terrains with less tree densities is Category C.

The basic path loss equation for SUI model with correction factors is given as,

$$L = A10\gamma\log\left(\frac{d}{d_{10}}\right)+\Delta L_f+\Delta L_h \qquad (22)$$

d is the distance between the base station and mobile station (m), d_0= 100m, γ is the path-loss exponent, $\Delta L_f$is the correction factor for the frequency, $\Delta L_h$is the correction factor for the receiver antenna height and s is the log normally distributed shadow factor due to the trees and other obstacles, having a value between 8.2 dB and 10.6 dB.

The term A, the path loss exponent and the correction factors in the above equation are given as,

$$A = 20\log\left(\frac{4\pi d_o}{\lambda}\right) \qquad (23)$$

$$\gamma = a - b h_o + \frac{c}{h_o} \qquad (24)$$

$$\Delta L_f = 6\log\left(\frac{f}{2000}\right) \qquad (25)$$

2.7 Egli Model

The Egli Model is a terrain model for radio frequency propagation, Egli model was first introduced by John Egli in 1957. This prediction model is applicable at frequency from 40MHz to 900MHz and linking range is less than 60Km. it was derived from real-world data on UHF and VHF television transmissions in several large cities. It predicts the total path loss for a point-to-point link. Egli observed that there was a tendency for the median signal strength in a small area to follow an inverse fourth-power law with range from the transmitter, so the model is based on planet earth propagation. The formulas for the Egli's propagation loss prediction model are as presented in (26) and (27):

For $h_m < 10$,

$$L_t(dB) = 20\log_{10} f_c + 40\log_{10} R - 20\log_{10} h_b + 76.3 - 10\log_{10} h_m \qquad (26)$$

For $h_m > 10$,

$$L_b(dB) = 20\log_{10} f_c + 40\log_{10} R - 20\log_{10} h_b + 76.3 - 20\log_{10} h_m \qquad (27)$$

2.8 Experimental Site

Propagation measurement was conducted in Osogbo (Long 4.5667° E, Lat 7.7667° N), the capital of Osun state, Nigeria. Osogbo is a city characterized by complex terrain due to presence of hills and valleys within the metropolis. The data was collected through a drive test which was done in a car en route the different locations. The figure 1 shows the location of Osogbo on the map and its surrounding towns using Google earth.

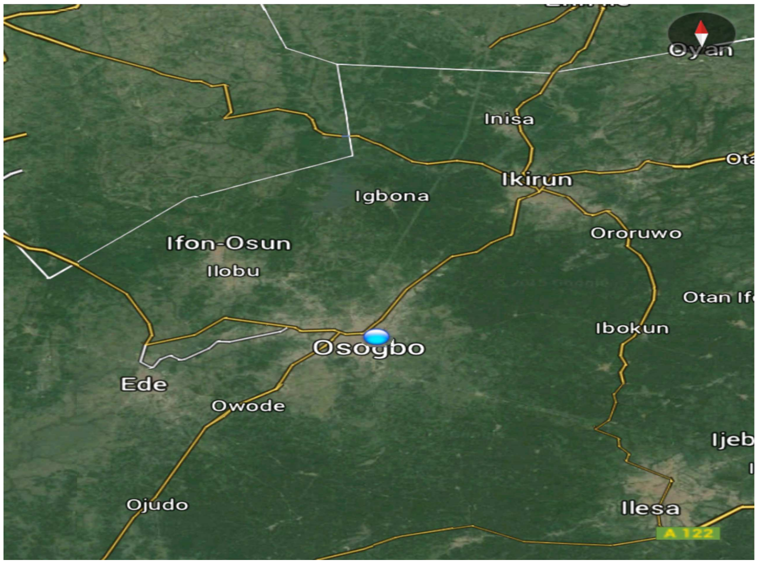

Figure 1: Map of Osogbo using Google earth

Table 1: Television stations in Osogbo and their transmission parameters

Television stations	**NTA OSOGBO**	**NTA IFE**	**OSBC**	**RTV**	**NDTV**
Frequency	695.25MHz	615.25MHz	559.25MHz	835MHz	479.25MHz
Channel	49UHF	39UHF	32UHF	66UHF	22UHF
Transmitting power	5KW	4.3KW	50KW	10KW	10KW
Antenna Height	152m	167m	340m	76m	198m
Type of transmitter	Analog, converted to digital	Analog	Analog	Analog	Digital
Repeater station	No Information Available(NIA)	NIA	NIA	NIA	NIA
Type of antenna	Omni directional antenna	Rhombic antenna	Isentropic antenna	Omni directional antenna	NIA
Coverage area	$\pm 60KM$	NIA	NIA	NIA	NIA
External gain of transmitter	3dB	NIA	NIA	NIA	NIA
Transmission Time	6am till 12 midnight everyday	4pm till 12 midnight everyday	6am till 12 midnight everyday	4pm till 10pm everyday	4pm till 10pm everyday
LATITUDES(Decrees North)	7.734831	7.500831	7.777574	7.633301	7.776829
LONGITUDE(Decrees East)	4.521286	4.590328	4.589412	4.158769	4.721137

The data was acquired from a secondary source which features the Field strength measurements recorded at intervals of 3km away from the transmitting site towards other stations using the field strength meter, the latitude, longitude and altitude recorded with the GPS receiver. The drive test was performed in several routes, with increasing distances from the transmitter and it was assumed that there was no additional loss incurred due to the mobile receiver being in the car and in motion. The routes are tabulated in Table 2. Of these 10 routes, route 1, 5 and 9 represents the longest routes for each of the transmitters.

Table 2: Defined routes for the field measurements

ROUTE NUMBER	ROUTE DESCRIPTION
1	RTV TO NDTV
2	RTV TO NTA IFE
3	RTV TO NTA OSOGBO
4	RTV TO OSBC
5	NDTV TO RTV
6	NDTV TO NTA IFE
7	NDTV TO NTA OSOGBO
8	NDTV TO OSBC
9	NTA IFE TO RTV
10	NTA IFE TO NDTV

The addresses of the television broadcast transmitters are highlighted:

1. Nigerian Television Authority, (NTA)Osogbo, New state secretariat, Osogbo
2. Nigerian Television Authority, (NTA) Ile-Ife, Mokuro road, off Moore road, Ile-ife.
3. Osun State Broadcasting Corporation (OSBC) Osogbo.
4. Reality Television (RTV) Iwo
5. New Dawn Television(NDTV) Ibokun

2.9 Measurement Set Up

The measurement set up comprised of a portable 2GHz field strength meter (SEFRAM RF Digital TV Meter) used to measure the field strength for each of the chosen television transmitter at varying reception points away from the transmitters, a hand held GPS receiver (GERMIN GPS 76, GERMIN GPS 76X) used to record the position of test points on the field, an antenna for better signal reception, a laptop computer for data logging, a mobile phone, used to check time which field data were taken and a car for moving around the transmitter with the equipment.

2.10 Calculation of Path Loss and Path Loss Exponent from the Measured Value

Path loss can be calculated using the data gotten from the drive test. The relationship between the power of the received signal and the transmitted power of the base station antenna gives us the linear path loss. To get the actual path loss, the following parameters would be taken into consideration [3].

Given the following parameters:

$P_R = Minimum\ receiver\ input\ power\ (dBm)$

$P_T = Transmitted\ power\ (W)$

$P_L = Path\ loss\ (dBm)$

$n = Path\ loss\ exponent$

$d = Radial\ distance$

$d_0 = Reference\ distance\ i.e\ 0.01$

$$P_L = P_T(dB) - P_R(dB) \tag{28}$$

$$P_T(dBm) = 10\log P_T(W) + 30 \tag{29}$$

Thus $P_L$becomes;

$$P_L = P_T(dBm) - P_R(dBm) \tag{30}$$

$$n = \frac{P_r(d_{\min}) - P_r(d_{\max})}{10 \times \left\{\log_{10}\frac{d_{\max}}{d_o} - \log_{10}\left(\frac{d_{\min}}{d_o}\right)\right\}} \tag{31}$$

2.11 Input Parameters for Predictions

The table below contains a list of all input parameters used throughout the course of this study, along with their symbols.

Table 3: Table showing parameters, symbols and units used for the path loss

Parameters	**Symbols**
Frequency	f(Hz)
Latitude	Φ(°)
Longitude	λ(°)
Altitude	H(m)
Radial distance	d(Km)
Band	(Hz)
Received power	$P_r(dbm)$
Transmitted power	$P_t(dbm)$
Path loss	$PL(dbm)$
Path loss exponent	PLE

Note that the path loss and path loss exponent estimation varies with the path loss models and is totally dependent on the latitude and longitude of the stations.

2.12 Optimization of the Propagation Path Loss Model

The path loss model to be optimized would be determined from the result of the simulation of data using EXCEL. Optimization would be done using the model that best fit with the path loss of the measured data (Free space path loss) with the introduction of a correction factor. The correction factor would be introduced in other to get the appropriate propagation model that would be suitable for path loss prediction here in Osogbo.

3.0 Results and Discussions

The tables below gives an overview of various results obtained from the experimental and theoretical aspects of this study for the path loss and path loss exponent of the different TV stations.

Table 4: Analysis of Results for the TV Stations

S/N	**STATION NAME**	**PATH LOSS EXPONENT(PLE)**
1.	OSBC	0.89927
2.	NTA OSOGBO	0.37843
3.	NTA IFE	-0.06544
4.	NDTV	-0.01151
5.	RTV	-0.07931

Table 5: Analysis of Results for OSBC

ROUTE NUMBER	**PATH LOSS EXPONENT(PLE)**
1	-0.01473
2	4.124605
3	0.846874
4	-0.19271
5	-0.00233
6	-0.04451
7	-0.08616
8	0.278421
9	-0.0162
10	1.08112

Table 6: Analysis of Results for NDTV

ROUTE NUMBER	**PATH LOSS EXPONENT(PLE)**
1	0.031993
2	0.000997
3	-1.31063
4	0.134904
5	-0.04375
6	0.401727
7	0.11554
8	0.031277
9	-0.02306
10	0.26468

Table 7: Analysis of Results for NTA ILE – IFE

ROUTE NUMBER	**PATH LOSS EXPONENT(PLE)**
1	-1.18522
2	-0.98999
3	-4.9356
4	-0.20623
5	0.70399
6	0.320075
7	2.182886
8	-0.25501
9	-0.03608
10	-0.07539

Table 8: Analysis of Results for NTA OSOGBO

ROUTE NUMBER	**PATHLOSS EXPONENT(PLE)**
1	-0.08474
2	-2.58553
3	0.034333
4	0.566152
5	-0.07008
6	0.420072
7	-0.43726
8	-0.19746
9	-0.02784
10	-1.14519

Table 9: Analysis of Results for RTV

ROUTE NUMBER	**PATH LOSS EXPONENT(PLE)**
1	-0.35149
2	-3.28111
3	3.673199
4	2.186167
5	0.002551
6	-0.54525
7	2.825506
8	0.348248
9	-0.12405
10	-0.40343

Table 10: Path Loss Exponents for Different Environments

Environment	***Path Loss Exponent, n***
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular Radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Path loss and path loss exponent was estimated for Osun as a sub-urban area. The result of the predicted Path loss exponent is as shown in Tables 4 - 9 above, for five TV stations in Osun state. Since the loss exponent from Table 4 cannot be compared with that shown in Table 10, its therefore neglected. From Table 5 OSBC route 2 as PLE of 4.124605 which ranges between 4 and 6 this implies that the signal strength decreases as a result of building obstructions.

From Table 7 NTA-IFE route 3 as PLE of -4.9356 this implies that the received signal strength is in the opposite direction decreases as a result of obstruction in buildings.

NTA-IFE route 7 as PLE of 2.182886 which implies signal strength decreasing with distance as a result of obstruction in factories. Table 4.4 NTA-OSOGBO route2 as PLE of -2.58553 this implies that the signal strength decreases as a result of obstructions in factories and is in opposite direction. Also, from Table 9 RTV Routes 2, 3, 4 and 7 as PLE of -3.28111, 3.673199, 2.186167 and 2.825506, Routes 2 and 7 falls within the path loss exponent for urban area cellular radio environment which theoretically ranges from 2.7 – 3.5 as shown in Table 10 while Routes 3 and 4 falls within obstructed in factories and shadowed urban cellular environments. The signal loss on the path of transmission varies, apart from the omitted Routes which show lesser exponent as a result of attenuation rate.

The following graphs shows the comparison between the field strength and the path loss attenuation for the different television stations.

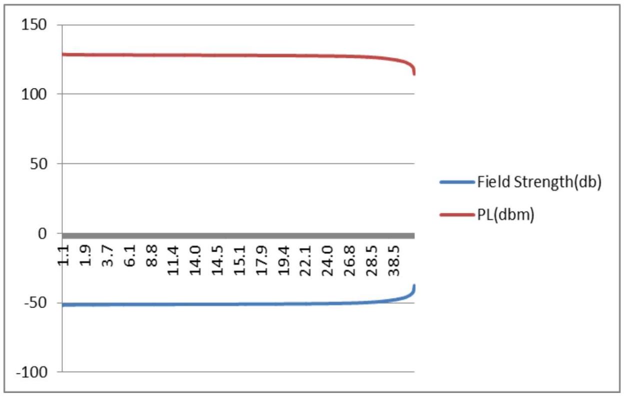

Figure 2: Field strength and Path attenuation loss pattern for OSBC

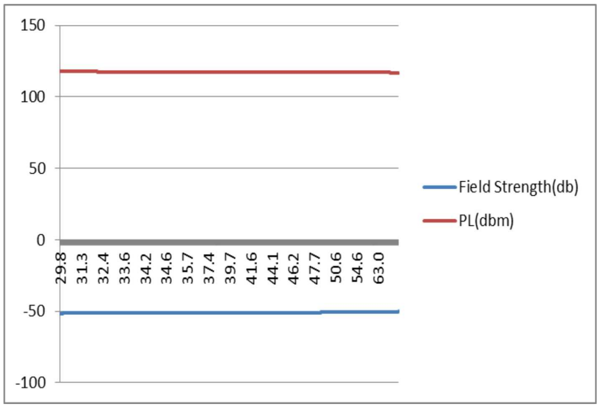

Figure 3: Field strength and Path attenuation loss pattern for NTA ILE - IFE

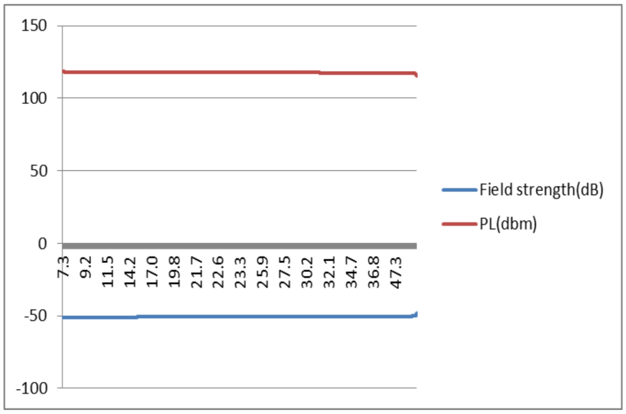

Figure 4: Field strength and Path attenuation loss pattern for NTA-OSOGBO

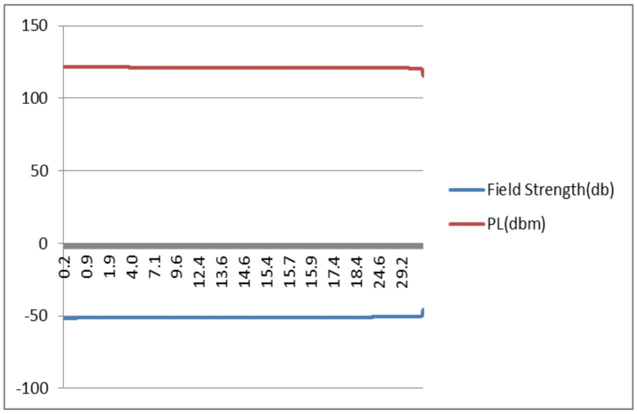

Figure 5: Field strength and Path attenuation loss pattern for NDTV

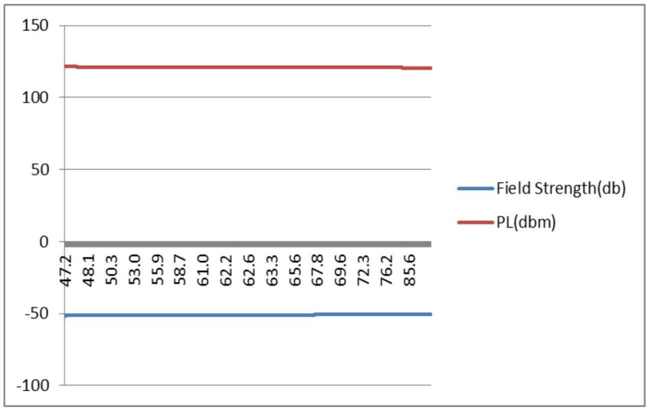

Figure 6: Field strength and Path attenuation loss pattern for RTV

By taking readings at various distances, it is possible to deduce some conclusions about the performance of the base station transmitter. It can be seen from Figures 2, 3, 4, 5 and 6 that the path loss increases as the received signal level decreases and this implies a decrease in the quality of service. The higher the path loss the lower the distance i.e. the relationship between path loss and radial distance is inverse proportion.

4.0 Conclusion

Propagation models are available to predict the losses in Television signals and thus they are not very accurate in determining the coverage area of a system. This is due to the fact that these models have been designed based on measurements in other places. Therefore, field measurements must support the path loss prediction models and path loss exponent for better and accurate results. The received signal level data collected over different distances from the base stations was used to estimate the path loss.

Firstly, the effect of different parameters, such as distance from base stations was studied and it is observed that path loss increases with distance due to a corresponding decrease in field strength.

Secondly, the observed results have been compared with six prediction models and it turns out that the COST-231 Hata model path loss values were closest of all the propagation model. Thus, the performance of COST-231 Hata model shows its suitability for path attenuation loss prediction in Osogbo. It also shows that the model can be useful for Television service providers to improve their services for better signal coverage and capacity for Receivers satisfaction in the studied area.

Finally, congestion of buildings also does obstruct greatly signal strength across board and thus hinders effective TV broadcast in coverage areas. Due to the differences in city structures, local terrain profiles, weather etc.

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