Investigating the Signal Strength in Digital Terrestrial Television Broadcasting Network: A case study in Ashanti Region

[1]K. A. Dotche, [2]W-N. Sibiri Bayor, [3]Willie K. Ofosu and [4]K. Diawuo.

[1]*Department of Electrical Technology Education ,University of Education, Kumasi-Ghana*
[2]*Department of Electrical Engineering ,Ecole Nationale Supérieure d'Ingénieurs (ENSI)-University of Lomé, Togo*
[3]*Faculty of Engineering Technology/ ,Pennsylvania State University ,Lehman, USA*
[4]*Department of Electrical & Computer Engineering University of Energy Natural Resources, Sunyani, Ghana*
Corresponding author: kdotche2004@gmail.com

Abstract

This paper presents an investigation on the distribution of the signal strength in digital terrestrial television broadcasting network in Ashanti region. The work intends to identify the feasibility limits of implementing the mobile digital television (DTT) network. A review on signals measurement both on small and large scale fading models used in the design are given in addition to the theory of signal distribution characteristics. It proceeds on signal characteristics using the distribution functions methods in order to predict the type of small-scale fading distributions that could characterize a given digital TV signal. The signal strength was obtained through measurement using a field strength meter. The Matlab software was used to analyse the data for the analysis.

The obtained results are much mitigated, but though they agree with some similar results obtained in the sub-region. We strongly believe that data span over large length would ultimately lift the clear picture of the small-scale fading distribution characteristics and the proposition to improve the theoretical model.

Keywords signal measurement, distribution function fitting, digital terrestrial TV

1. Introduction

The migration to digital transmission in TV broadcasting involve some challenges, such as the information coding, the medium attenuation, and the protocol for the digital terrestrial TV, to this demand comes the mobile TV reception. The medium attenuation [1], [2] would need to be optimized when installing a digital TV receiver

The Digital Terrestrial Television (DTT or DTTV) is an evolution of the broadcast television in other words, an advancement of analogue television. The implementation requires digital technology that would provide a greater number of channels in one hand. On the other hand, the quality of the picture and sound are concerned using a conventional antenna instead of satellite dish or cable. The purpose of the DTT is to reduce the use of spectrum, and provide a higher channel capacity than analogue. It also aims at lowering the operational cost for broadcast and transmission (after the initial upgrade costs). The deployment of such system call for the understanding of the theory on the radio frequency wave modelling. Satisfactory theoretical contents, particularly on signal attenuation are reported in [3], [4] and [5].

However, on issues concerning the digital terrestrial TV, very few data are available about the Africa exposure to the hit. The signal distribution, allows the design system engineer to choose a safety margin.

This paper seeks to investigate the received TV Signal strength distributions with respect to the weather condition experience in Ashanti region, Ghana. The rest of the paper is organized as follows. The related works are presented in section II. The next section depicts the distribution models. The section IV, presents the data collection methods and the software used in the analysis. The obtained results are discussed in section V. The conclusion is given in the section VI.

2. Related Works

Friis [6] had observed in 1947 that in free environment impairment that could be approximated to ideal medium, the decay rate of signal strength attenuation is about 20dB/decade. In 1957, Egli [7], made usage of dataset measurement carried out in some locations in United States of America at 40 Mega-cycle (MHz) to fit the theoretical plane-earth propagation model out of which he developed a set of curves (nomograms) for signal prediction over an irregular terrain for broadcasting stations and mobile transmission services. The Egli contribution is a factor of 40 over mega-cycle squared to the plane earth model given a decreased rate of the signal strength at fourth power against the distance in cluttered environment and fourth against the frequency. However, the work did not quantify explicitly the effect of diffraction to due terrain features. Over the average terrain, Egli reported a logarithmic standard deviation value around 8.3 dB and 12 dB for shadow fading at VHF and UHF frequencies, respectively. Meanwhile, Okumara et al., conducted a vast drive-test measurement in Kanto and Tokyo regions, Japan; Okumura et al., [8] investigated the decreased rate in signal strength against the distance, and observed a higher value than that predicted by Friis.

Okumura et al., then developed some curves known as the "median" path loss prediction in 1968 [8] for identified clutters. Hata [9], on the other hand derived some mathematical formulations to fit Okumura curves for the different environments. The Hata model [9] takes into account the graphical information of the Okumura model and incorporates the effects of diffraction, reflection and scattering because of structures along the path. He considered urban clutter as a basis of his model to which correction factors are been supplied to meet others. The work of Hata was not oriented on the statistical components of the signal strength but did implicit its decreased rate as a function of the transmitting antenna height. In [10], the statistical property of the signal strength envelope was quantified to be a composite of fast fading signal and slow fading signal [7] due to the user mobility. The fast fading magnitude was obtained on an average number of finite sample measurements, but the slow fading consisted to take an average of wide measurement over distance [10]. In 1980 era, Delisle et al., [11] performed analytical studies on some prediction models such that of Egli, Hata [9], Allsebrook and Parsons, Edwards and Dukin, Blomquist and Ladell. Their study illustrated a clear analysis with a chronological order of these models and showed out the substantial means compensated by different authors using some comparative plots. In contrary, Ikegami et al., [12] made use of a deterministic approach in the theoretical signal prediction that relied on ray tracing by making usage of clutter database information and derived a theoretical prototype for signal prediction. The model was then compared to measured data obtained at 400MHz in Kyoto downtown. Xia and Bertoni [13] focused on wave dispersion at structures' edges with help of Boersma function [14], and developed a prototype that was compared favourably with measured data on diffraction effect due to multipath propagation observed in cluttered environment. Multipath effect is dependent on the environment clutter. An approach of the environment clutter classification was proposed using Fuzzy logic [15] model. The algorithm assumed the slope of path loss model by defining a finite clutter where the path loss exponent could be obtained from measurement. The theoretical models of Hata and Walfisch-Ikegami have been used for validation [15]. In [16] Thomas et al., performed a study of some of the propagation models such as Longley Rice, Walfisch and Ikegami etc., and stated their area of application. It is also interesting to recall that, signal prediction accuracy relies in space and in time. In improving the signal prediction for mobile cellular services the European Cooperation in the field of Scientific and Technical Research (COST) committee have shown a great concern on this issue and have conducted a vast drive-test measurement in European cities. They have proposed a modified prediction of the Hata-Okumura propagation model to suit the UMTS services, which was known as COST231. Furthermore, Walfisch and Ikegami research works in signal prediction have modified the COST231. The model has then been named COST-Wi, which included the effect of street canyon ray. The parameters' coefficient in Hata-Okumura model have been optimized to fit the measurement data collected in London Suburban by the use of least square algorithm [17]. In [18], the agreement with Hata-Okumura [9] and Lee [18] prediction model measurement data was investigated in a rural area in a small town of Purwokerto, Central Java (Indonesia). The results have shown that less path loss have been obtained for short distances but for long distances, the model gave higher path loss. This was on contrary with Hata model performance in open area and built-up area observed in [16]. In [19], a similar analysis was done using Lee's model to fit measured data, in Saudi Arabia, the model showed a better agreement. The study in [20] modified the linear regression model of the distance, which was applied to measurement data and derived the decreased rate and the offset of the signal strength by using the Least Mean Square (LSM) algorithm as in [21]. The derived model has been compared to COST-231, and COST-Wi, etc., with the measured

data collected in urban area clutter of Amazonas in Brazil. In [22], the path loss study was conducted by using ray tracing for field strength analysis. Similar research on the prediction of the field strength inside buildings was investigated using neural network approach in [23], The work focused on theoretical analysis of reflected rays which could be used to quantify the attenuation in signal strength due to diffraction [24].

In Africa, signal strength predictions are not much covered particularly in West-Africa but a steering work is on the way such as, the reference [25] reported the Weibull distribution to better describe the signal fading over short distances in cellular networks Ghana. However, the variation of the wind speed at the west Africa coast could also be described by the Weibull distribution. The work in [26] invetigated the Hata's and COST-231 models with measured data in Greater Accra, Ghana and Ouagadougou, Burkina-Faso. Similar work was reported in [27], using the Stanford Interim and the COST 231 models in Togo. The studies in [26]-[27] indicated that these empirical models could show in a little agreement with some measured data. However, the authors pointed out that the response of these models were much related to the undulating terrains. In the design of digital TV broadcasting network, the propagation models of the International Telecommunication Union ITU R-370 and ITU R-1411 are intensively used [28].

The migration from the analogue TV to the digital terrestrial TVs is calling for further investigation of this type of transmission and its response to the tropical climate environment But, it could be admitted that very few work on signal distribution are reported in the literature. This scope remains the true validation of the work presented in this paper. Some measurement data were conducted on signal strength on the digital terrestrial TV broadcasting installation in the Ashanti region, in Ghana. The paper investigates the distribution functions that best describe the data for further predictions in this feasibility study.

3. The Theoritical Models

The reference [25], provides the literature on the distribution functions developed in this section, A standard normal distribution of a random variable X is a special class of distributions that has a mean, of zero and a standard deviation, σ^2 , of 1. Its PDF is given as:

$$f(X) = \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(X-\mu)^2}{2\sigma^2}] \qquad (1)$$

The PDF of the lognormal distribution of a random variable X is given as

$$f(X) = \frac{1}{X} \times \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(lnX-\mu)^2}{2\sigma^2}] u(X) \qquad (2)$$

It should be noting that ln(X) has a normal distribution. This distribution has two parameters μ and σ.

The Rayleigh distribution has a probability density function (PDF)

$$f(X) = \begin{cases} \frac{X}{\sigma^2} e^{\frac{-X^2}{2\sigma^2}}, & (0 \le X \le \infty) \\ 0, & (X < 0) \end{cases} \qquad (3)$$

where σ is the rms value of the received signal before envelope detection, and σ^2 is the time-average power of the received signal before envelope detection.

The probability that the envelope of the received signal does not exceed a particular threshold value R, the corresponding PDF is given as

$$f_X(R) = f_X(X \le R) = \int_0^R p(X)dX = 1 - e^{\frac{-X^2}{2 \times \sigma^2}} \quad (4)$$

The rms value of the envelope is the square root of the mean square, and σ is the standard deviation of the measured received signal to envelope detection.

The Rician distribution is described by the component of a dominant stationary signal, given as

$$f(X) = \left(\frac{X}{\sigma^2}\right)e^{\left(-\frac{X^2+A^2}{2\sigma^2}\right)}I_0\left(\frac{A \times X}{\sigma^2}\right)u(X) \quad (5)$$

with the parameter A that represents the peak amplitude of the dominant signal, and Io is the modified Bessel function of the first kind and zero order.

The PDF of the Weibull distribution for a given random variable X is expressed as

$$f(X,a,b) = \begin{cases} \frac{b}{a}\left(\frac{X}{a}\right)^{b-1}e^{-\left(\frac{X}{a}\right)^b}, X \ge 0 \\ 0, X < 0 \end{cases} \quad (6)$$

Where $b > 0$ and $a > 0$ respectively the shape and scale parameter, of the distribution. Its complementary cumulative distribution function is a stretched exponential function.

The computation of the root mean squared error (RMSE), the correlation coefficient R^2 and Relative RMSE (RRMSE).

The RMSE parameter provides the difference between the predicted value x_i and observed value y_i for N data samples [29]. The ideal value is zero (0). It is given as

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_i - x_i\right)^2} \quad (7)$$

The cross-correlation coefficient, its ideal value is one (1) that gives the correlation between the predicted and measured values given as

$$R^2 = \frac{\sum_{i=1}^{N}\left(x_i - \overline{x_i}\right)\left(y_i - \overline{y_i}\right)}{\sqrt{\sum_{i=1}^{N}\left(x_i - \overline{x_i}\right)^2 \cdot \sum_{i=1}^{N}\left(y_i - \overline{y_i}\right)^2}} \quad (8)$$

The auto-correlation is given by

$$R^2 = \frac{\sum_{i=1}^{N}\left(x_i - \overline{x_i}\right)}{\sqrt{\sum_{i=1}^{N}\left(x_i - \overline{x_i}\right)^2}} \quad (9)$$

The RRMSE is obtained by dividing the RMSE of signal strength characteristics (Means, standard deviations and power densities of signal strength) obtained by the average measured values as follows:

$$\text{RRMSE (\%)} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_i - x_i\right)^2}}{\frac{1}{N}\sum_{i=1}^{N}y_i} \cdot 100 \quad (10).$$

If a path length d, runs over N different areas, and has N different path loss slopes n_i (such $i = 0, ..., N-1$), the mean path loss P_{Lmean}, [26] is given as

$$PL_{mean} = 10n_0 log\left(\frac{\lambda}{4\pi d_0}\right) + 10n_1 log\left(\frac{d_0}{d_1}\right) + 10n_2 log\left(\frac{d_1}{d_2}\right) + \cdots + 10(N-1) log\left(\frac{d_{N-1}}{d_N}\right) \quad (12)$$

$d_{N-1} < d < d_N$, and when accounting for different shadowing attenuation at various locations yields the allowable path loss PL_{al} given as:

$$PL_{al} = 10n_0 log\left(\frac{\lambda}{4\pi d_0}\right) + 10n_1 log\left(\frac{d_0}{d_1}\right) + 10n_2 log\left(\frac{d_1}{d_2}\right) + \cdots + 10n_{N-1} log\left(\frac{d_{N-1}}{d}\right) + X_{\sigma_{n_0}} + \cdots + X_{\sigma_{n_{N-1}}} \quad (13)$$

with $X_\sigma(dB) = E\left[X_{\sigma_{n_0}} + X_{\sigma_{n_1}} + \cdots + X_{\sigma_{n_{N-1}}}\right]$

where E is the statistical mean.

If the antennae gains are included, the received power is formulated as

$$p_{R_x}(d, X_\sigma) = m * g_{Tx} * g_{Rx} * d^{-n} \quad (14)$$

where m is a constant expressed in [26] as:

$$m = p_{T_x}(h_{BTS} * h_{MS})^n * \left(\frac{c}{4*\pi}\right)^n * \left(\frac{1}{f}\right)^n * X_\sigma \quad (15)$$

Noting that the received power could be written as function of the signal to noise ratio [28] as:

$$snr_{input} = p_{Rx}/kTB \quad (16)$$

The output signal to noise ratio at the receiver is as

$$snr_{output} = \frac{p_{Rx}}{kTB} * 1/f \quad (17)$$

Where k is the Boltzmann constant, T, the ambient temperature, B the bandwidth and f the form factor.

4. Methodology

Data were collected, with the aid of a field strength meter. The measurements were conducted within the range of about 1 to 10 km from the Ghana Broadcasting Cooperation (GBC) station in Kumasi. The measurements were also done for receiving antenna heights of 1.5m and 10m. The RF parameters are given in Table 1

Table 1. Radio parameters

designation	value
Elevation of the transmitter	260m
Operating frequency	625 MHz
Transmitter height	93m
Transmit power	2KW
Antenna Gain	12dBi
ERP	31KW (45dB)

Data collection spanned from 10th July 2013 – 30th May 2014 with each day having its set of values. Once the received signals were captured, the information such as the signal strength, the Bit Error Rate (BER), and the Signal-to-Noise ratio (SNR) were recorded for the digital TV receiver at a distance far away from the transmitter.

The graphs were generated in Matlab software, using some toolboxes such as cftool, for the data fitting, and dfittool for the distribution functions analysis.

5. Results and Discussion

This section presents the analysis of the data and discusses the closeness to the state of art and theories develop in the previous sections.

The Figure 1 shows the coverage map taken into account the measured data, the SNR, BER and the signal strength. It may indicate that the lower high of the receiver translate a higher interference.
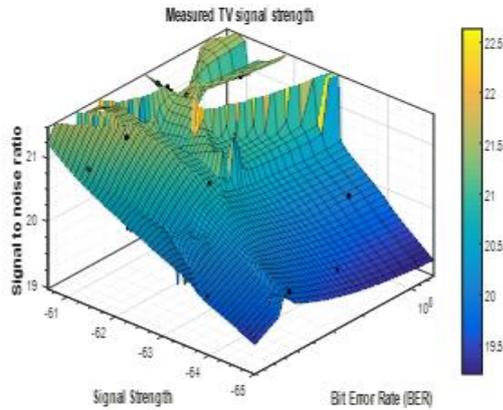

Figure 1: Received Coverage by the 1.5 m digital receiver

This may be explained by the sharp curve in the coverage. However, the analysis of the coverage area for the 10m digital receiver may indicate a smooth coverage.
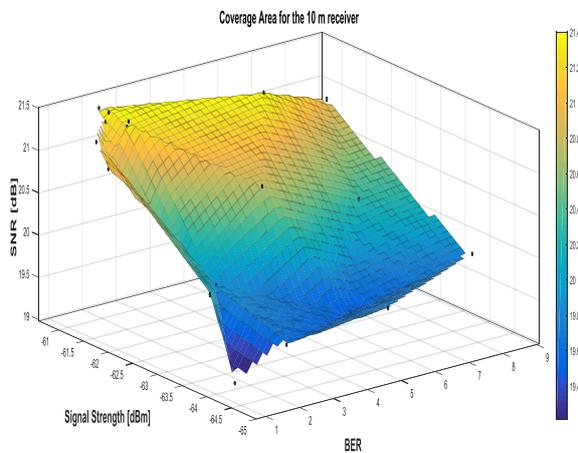

Figure 2: received Coverage by the 10m receiver.

The main difference between the observed data in Figure 1 and 2 may illustrate that a higher height of the receiver translate a higher gain, this explains a less exposure to the environment clutter.

The Figure 3, shows the distribution of the signals by considering the measurement of the digtal receiver placed at 1.5m

It should be recalled that, at 10 m above the ground, the received signal was excellent.

The other aspect is to seek at which possibility the mobile TV could be ventured by mobile operators. This emphasis the idea to consider the data of the digital receiver at 1.5m above the ground.
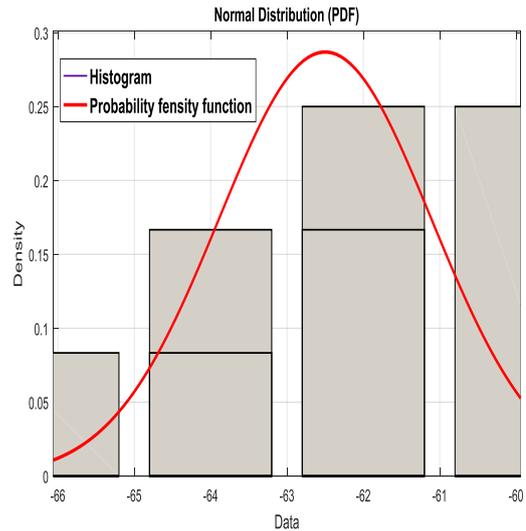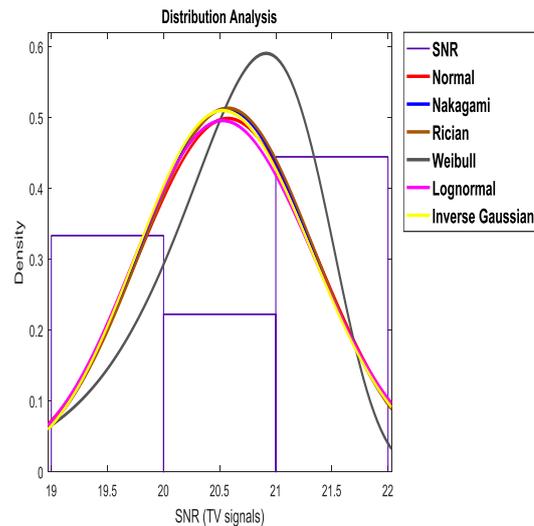

Figure 3: Distribution Analysis

Figure 4: Analysis of the signal strength to the SNR

In Figure 4, it is observed that the Weibull distribution function may give a close agreement to the data distribution.

The long-term parameters are obtained by a fitting method using the cftool toolbox in matlab. The statistic of the fitting parameters using a linear model are given

$$f(x) = a*(sin(x-pi)) + b*((x-10)^2) + c$$

Coefficients (with 95% confidence bounds):
    a =   -0.8129 (-1.587, -0.03837)
    b = -0.0002564 (-0.003596, 0.003083)
    c =   21.78 (4.081, 39.47)
  SSE: 1.069
 R-square: 0.9017
 Adjusted R-square: 0.8886
 RMSE: 0.2669

The value of the C-parameter in the signal strength data, gives the shadow area attenuation in the digital signal strength. Is thereby the most important, because this quantifies the effect of the shadow-area.
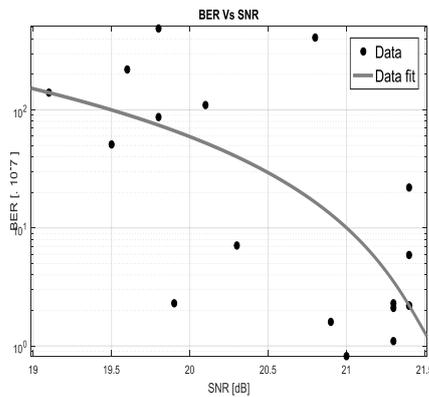
Figure 5: The Received BER against the BER

The BER and the SNR describes the quality of the modulation scheme. The modulation scheme was 64 QAM. It should also be underlined that when the receiver height is low, the BER could be high.

Table II statistical parameters of the sample (1.5m)

Distance [km]	Path loss exponent n	Receiver [dBm]	SNR [dB]
9	2.2	-48.3	19.3
6	2.1	-43	26.8
5	2.2	-48.9	26.23
4	1.8	-40.96	25.75
3	1.8	-42	24

The analysis of the path loss exponent may indicate that the signal decay is really close to that predicted by the Friis and the medium could be assumed to a guided wave, since the path loss exponent is close to two. Therefore, the height of the receiver could be said to not comprise the reception while using a mobile phone thus the reception of the mobile TV could be implemented using the ITU-R 370 model with some appropriate fitting parameters.
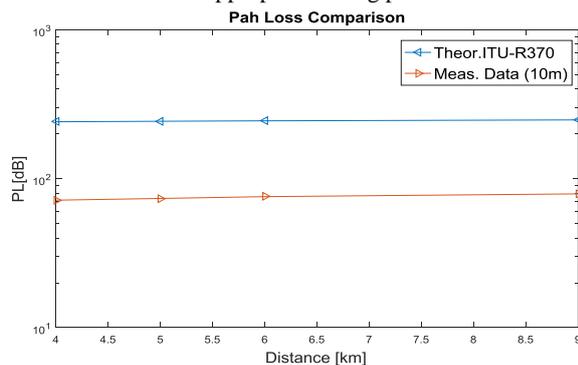

Figure 6: Comparison of ITU-R 370 and data

The figure 6 indicates that the ITU-R 370 models may need some more fitting parameters in order to give an agreement with the data by the help of some tuning algorithms.

6. Conclusion

The work presents the analysis of the signal strength obtained from a digital TV receiver.

The main finding about this work is that the radio signal envelope could be closely described by the Weibull's distribution, in the costal West Africa. These results could be said to agree with the obtained data on the small scale fading in cellular network [25] and that of the study on the wind speed observed over the short term analysis in [29].

It should be noted that, the bit error rate selection is accordingly done by Erlang chart [30] knowing the signal to noise ratio. If there is available data on the characteristics of the distribution functions of the field strength, it will not be necessary to refer to the Erlang

table in the selection of the BER. Further measurement could help in decision making to appreciate the small scale fading experience in digital broadcasting terrestrial TV network in the region.

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