Propagation Models Calibration in Mobile Cellular Networks: A Case Study in Togo

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***Abstract*—Many efforts have been made to come out with some propagation models that should be suitable to the area of interest. Therefore, this raises the issue of the environment and its characteristics. This perspective has led to environment's classification with some specific models, which in turn are embedded in planning and optimization software. Software is very expensive in addition to the calibration of the embedded prediction models may require an extra cost for the network operator(s). This vision has prompted the work developed in this paper. This paper presents a calibration of the European Cooperation in the field of Scientific and Technical Research (COST) COST-231 model and that of the Standard University Interim model to field data in some selected environment study of Togo. The work not only proposed some optimized fitting parameters suitable for the environmental conditions in Togo, but provides consistent statistical parameters for these models for future electromagnetic applications but though cellular operating frequency has been considered in this work.**

Keywords—Propagation models tuning; COST-231; SUI-Model; received signals; drive testing

I. Introduction

Propagation models are heavily used at various stages of the planning and optimization processes in cellular networks, not only but also broadly in the telecommunication networks. These prediction models help in the forecasting of the medium's fading that affects the transmitted signal to the received signal vice versa. The signal's attenuation in a given geographical area to be served influences the planning steps in the network topological layout configuration and the cell's capacity. Many works in signal prediction are conducted to find out which of the propagation models that should be suitable to a given area of interest. Wave propagation modeling is widely covered in the literature as in [1]-[4]. Many electromagnetic prediction tools are embedded in planning and optimization software.

Earlier works of Friis [4] investigated the decreased rate of signal strength attenuation and came out with a value of 20dB/decade. This finding was applicable for situations where the electromagnetic wave [3] is propagating in free space medium a typical case of ideal condition without impairment between the transmitter and receiver against the distance of separation. With Friis hypothesis, the model does not consider the effect of ray scattering, reflection as well as diffraction. In practical environment with presence of clutter, the signal prediction for mobile cellular services was carried out to suit the European's environment by the European Cooperation in the field of Scientific and Technical Research (COST) committee, subsequently through 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 is then called COST-231 [4]. In [5], the Hata Okumura's model was compared to the measured data while using code division multiple access CDMA-2000 voice-activity signals in Greater Accra. The model's response has shown a little agreement against the measured data though highly directional antennas were used. Thereby, the least square fitting method was applied to derive the optimal offset and the decay rate of the signal attenuation in view of optimizing the theoretical model in Great-Accra. The [6] investigated the Hata Okumura and the COST 231 models in Ouagadougou in Burkina-Faso, against Global System for Mobile communications' (GSM) signals. The obtained results have also shown a little agreement with the measured data. It was pointed out that the high transmitting power of the transmitters could have resulted in this discrepancy observed in the models response. The clutter was reported to be a flat terrain. However, not enough information about the measurement conditions was given. The fast fading distributions models were evaluated in a noisy mobile cellular environment in Ghana by crossing some theoretical prediction models to data obtained from a drive test system [7]. The small scale fading models, including the Weibull's distribution function have been compared to the data. The results have indicated that the Weibull's fading distribution gave a closer description of the experienced fast fluctuations in Ghana. The signal variation components such as the fast-fading, the signal decay have been estimated using a statistical method out of a series of GSM signals measurements in Benin-City (Nigeria) [8]. The results have come out with a path loss exponent value in the range of 2.8 to 3.7 shadow-area value of 12.3 dB. The work in [9] investigated the Hata model with measured data in Greater Accra. The study has shown that the Hata's model may present a little agreement with measured data; the authors have indicated some of the areas may not correspond to Hata-clutter. In [10], the propagation channel characteristics as function of the frequency using a digital signal processing, a linear predictive coefficient were carried out. The work has come out with the local mean fading value about 7dB in the city of Lomé, Togo.

This paper investigates the propagation models in a cross comparison with measured data while considering some selected environment in Togo. The work further optimized the Hata-Okumura and SUI models using a statistical method. The rest of the paper is organized as follows: Section II presents the large scale model, and Section III, the measurement environment condition and the tools used. The Sections IV and V discuss and elaborate the results and conclusion, respectively.

II. THEORICAL MODELS

The COST-231 model [5] is given as:

$$L_p = 46.3 + 33.9 \ \log\left(f\right) + \left[44.9 - 6.55 \log\left(h_b\right)\right] \log\left(d\right)$$
$$-13.82 \ \log\left(h_b\right) - a + C_m + a_2 \tag{1}$$

This can be written as:

$$L_p = 46.3 + 33.9 \ \log_{10}\left(f\right) + a_1 \log_{10}\left(d\right)$$
$$-13.82 \ \log_{10}\left(h_b\right) - a + C_m + a_2 \tag{2}$$

$$L_{COST23} \left[dB\right] = A_1 + B \ \log_{10}\left(R\right) + C_1 \tag{3}$$

Where,

$$A_1 = 46.3 + 33.9 \ \log_{10}\left(f_C\right) - 13.82 \ \log_{10}\left(h_{BTS}\right) - a\left(h_{MS}\right) \tag{4}$$

$$B = 44.9 - 6.55 \ \log\left(h_b\right) \tag{5}$$

$a(h_{MS})$ is a correction factor for the receiver antenna given as for suburban environment:

$$a = \left[1.1 \ \log 10\left(f_C\right) - 0.7\right] h_{MS} - \left[1.56 \log_{10}\left(f_C\right) - 0.8\right] \tag{6}$$

and C_1 is the clutter correction factor given as follows:

$$C_1 = \begin{cases} 0 & for \quad medium \quad cities \quad environment \\ 3 \ for & metropolitan \quad areas \end{cases}$$

$$L_{COST231} \left[dB\right] = \left(A_1 + C_1\right) + B \ \log_{10}\left(R\right) \tag{7}$$

The Stanford University Interim (SUI) model identifies three types of environment clutter. These are as follows:

Other characteristics of the model are:

- Cell-size about 10 km in radius;
- The mobile receiver antenna height between 2 and 10 m;
- The transmitter antenna height between 15 and 40 m.

The model transmission loss L_P is given as:

$$L_p \left[dB\right] = A + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + S + L_f + L_h \tag{8}$$

where, A and γ are defined as for $d > d_0$.

$$A = 20 \log_{10}\left(\frac{4\pi d}{\lambda}\right) \tag{9}$$

$$\gamma = a - b h_b + \frac{c}{h_b} \tag{10}$$

The coefficients a, b, and c for the various the clutter are given in Table 1.

TABLE I. COEFFICIENT OF SUI MODEL RESPECTIVE TO THE ENVIRONMENT CLUITTER

	Type A	Type B	Type C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

- L_f and L_h are correction factors respectively for the frequency above 2GHz, and the mobile receiver height between 2 to 10 m;
- S is the shadowing effect, $8.2 \ dB < S < 10.6 \ db$.

The factors L_f and L_h are formulated as:

$$L_f = 6 \log_{10}\left(\frac{f}{2000}\right) \tag{11}$$

$$L_h = \begin{cases} -10.8 \log_{10}\left(\frac{h}{2}\right) & for \quad types \ A \ and \ B \ clutter \\ -20 \log_{10}\left(\frac{h}{2}\right) & for \quad type \ C \ clutter \end{cases}$$

The measured path loss at any point y_i is expressed as:

$$y_i \left[dB\right] = ERP - P_{Rx_i} \tag{12}$$

Where,

$$EPR\left[dbW\right] = P_{T_X} + G_{T_X} + G_{R_X} - C_{loss} \tag{13}$$

In sum, the model could be written as:

$$L_{COST\,231}[db] = b + a\log_{10}(R) \tag{14}$$

$$b = A_1 + C_1 \tag{15}$$

The mean error (ME) obtained from the statistical distribution [11] is given as:

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{n} X_i \tag{16}$$

The mean square error (ME) [11] is formulated as:

$$M = \sqrt{\frac{\sum_{i=1}^{M}\left|X_i - L_p\right|^2}{M}} \tag{17}$$

X_i the signal at a point (i), L_p the signal threshold (e.g. reference signal level).

Thus, in the process to optimize a theoretical model, the error will be carried out with respect to the site data. The error (Error) is the difference in value between the predicted model and the data could be expressed as:

$$L_{Measured}[dB] = L_{Theoretical} \pm Error \tag{18}$$

It will be noted that all the algorithms used in this work have a base 10.

III. Methodology

The data collection consisted of using a drive test system [5], [6]. The data analysis method debunks from the vast majority in signal measurement. Firstly, the least algorithm was used to find the offset and the decay values for each selected clutter in accordance to the clutter belonging. The second approach consisted to map the various clutter accordingly, and carried out their statistical mean and the error margin on the obtained values provided by the least square algorithm. This method really reduced the error on the estimated value and rendered the precision much closer.

The choice of the environment clutter is as follows. The type A, yields a maximum transmission, which is assumed to be moderated thick leafy trees, with densely congested buildings. The type B, may incur an average transmission loss, a typical accidental hilly terrain with intense vegetation. The C, the transmission loss is the lowest, an area alike flat terrain with intense vegetation are respectively the urban, suburban and the rural areas prior identified by the network operator.

The method used in this work combines the features of the least square regression [5], and the statistical averaging [11] algorithms.

The RF parameters are as follows node B, height h_b = 30m (varying); a mobile unit height h_m = 1.5 m; a frequency f = 2145 MHz; a transmitting antenna outpout power = 43 dBm (varying); a Transmitting antenna gain G = 18dBi, where the mobile unit antenna gain was set to a default value of 0dBi. The cable, duplexes and connectors loss were estimated about 2dB.

IV. Results and Discussion

The measured data and the theoretical optimized models are presented in this section.

The optimized parameters in the COST 231 and SUI model (a_1 and a_2) are given in Tables 2 and 3, respectively. The calculated errors on these models to the data are given in Table 4.

TABLE II. Coefficient in COST -231 Model Respective to the Environment Cluitter

	Urban	Suburban	Rural
a_1	-5.4049	-3.9906	-5.7691
a_2	-83.5555	-90.6498	-86.1344

In Fig. 1 to 3, are depicting the derived models. The yellow the overall model to suit the environment of Togo, and the red plot the subsequent for the different clutters such as urban, suburban and rural identified by the cellular network operator and consistent to Hata-Okumura type of clutters.

The scattered plot (in blue) indicates the measured data. The yellow curve is the overall derived from the regressive prediction model for the overall clutter of Togo meanwhile the red plot is specific to the environment clutter type.

The urban model is obtained as:

$$Urban_{model} = 29.82\log_{10} x + 58.087$$

The overall derived prediction is much closer to the specific prediction. The overall, may indicate that the clutter in study depicts significant correlation to be the Hata suburban (Fig. 2 and 3).

The suburban model is given as:

$$Suburban_{model} = 31.234\log_{10} x + 49.4721$$

and the rural model is as:

$$Rural_{\ model} = 29.4558\log_{10} x + 53.9875.$$

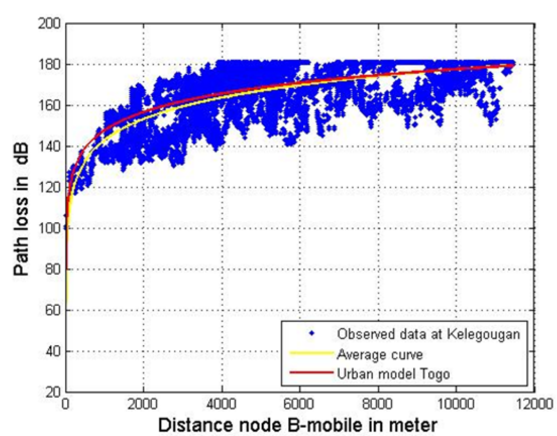

Fig. 1. Derived model and Actual model in Urban.

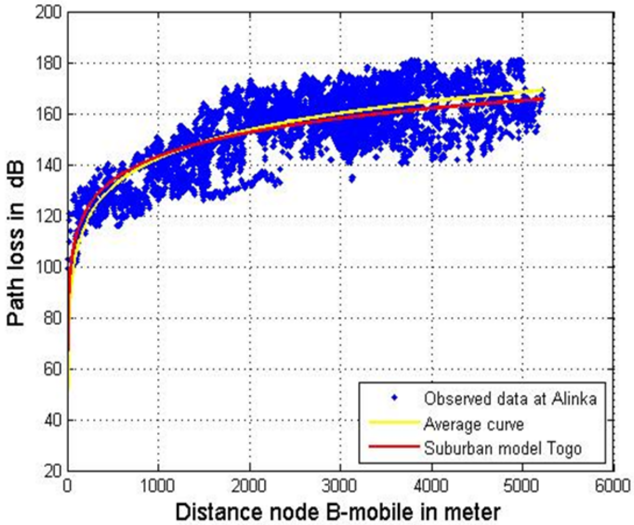

Fig. 2. Derived model and Actual model in suburban.

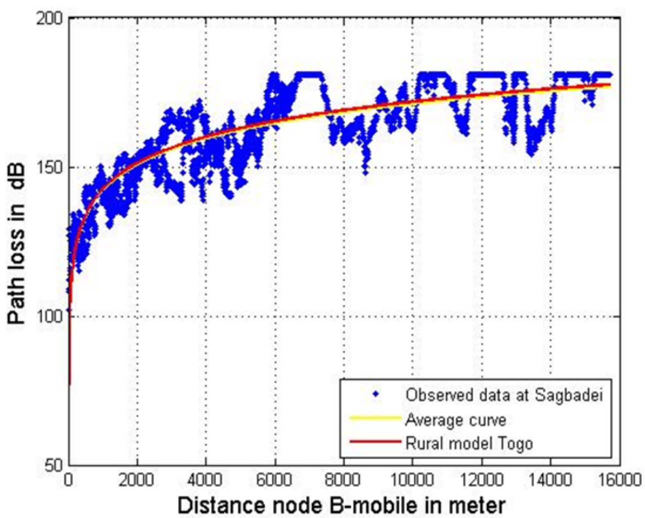

Fig. 3. Derived and Actual models in rural area.

TABLE III. THE OPTIMIZED PARAMETERS IN THE SUI MODEL RESPECTIVE TO THE TYPE OF CLUTTER IN TOGO

	Type-A		**Type-B**		**Type-C**	
	Optimized	**Initial**	**Optimized**	**Initial**	**Optimized**	**Initial**
a’	2.7870	4.6	2.7484	4	2.4289	3.6
b’	0.0075	0.0075	0.0065	0.0065	0.005	0.005
c’	12.6	12.6	17.1	17.1	20	20
e	27.7250		21.9381		21.7474	

V. CONCLUSION

Data obtained in some cities in Togo on mobile communication field installation have been investigated against the Hata-Okumura and SUI models. A statistical based upon averaging and least square regression methods were used. The results have indicated that these models may need some fitting parameters for a better coverage and capacity optimization. With help of a wide drive testing, some correction factors have been drawn. However, it will be recommended that updated seasonal data should be made available for accurate prediction of these parameters. The current approach do not quantify the attenuation due to trees, neither the diffraction caused by the earth path profile that would provide information about the air-interface optimization nor for other future electromagnetic applications in the country.

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TABLE IV. COEFFICIENT OF SUI MODEL RESPECTIVE TO THE ENVIRONMENT CLUITTER

Sites	**SUI Model**						**COST 231-Hata Model**			
	Urban		**Suburban**		**Rural**		**Urban**		**Suburban and Rural**	
	ME	MSE	ME	MSE	ME	MSE	ME	MSE	ME	MSE
Adanka	15.7417	17.3063	8.5261	10.0706	5.2374	6.7340	10.2956	10.4257	8.7750	8.9273
Adéticopé	8.3417	10.3195	2.1138	4.7491	0.5674	3.1827	5.8880	5.9140	4.3674	4.4023
Agbodrafo	1.2084	6.4503	5.5123	7.1196	8.4966	9.1443	2.7383	2.8502	4.2589	4.3317
Agbonou	6.3588	13.2865	0.8747	9.8861	1.3491	8.8323	6.1586	8.7075	4.6380	7.7073
Akparé	13.2872	15.5819	5.9988	8.7086	2.6654	5.8343	7.6206	8.0540	6.1000	6.6335
Alinka	1.3440	4.8490	6.7377	7.3133	8.9059	9.0719	1.2704	1.5233	2.7910	2.9148
Amaoudè	1.1153	7.0298	5.6356	7.6102	8.6385	9.5157	2.9228	3.2438	4.4434	4.6608
Amédenta	0.4996	5.5339	5.8144	6.8881	8.5486	8.9279	2.2151	2.2151	3.7357	3.7357
Amouoblo	11.6130	13.4820	4.5842	6.7991	1.4105	4.1446	6.7330	6.8596	5.2124	5.3749
Aouda	11.8294	13.6165	4.5066	6.6683	1.1519	3.9615	6.0583	6.1767	4.5377	4.6946
Assiyéyé	9.5890	11.6832	14.6825	15.4663	16.6660	17.0818	8.6057	8.6863	10.1263	10.1949
Atchangbadè	4.4189	8.5426	2.4378	6.0007	5.5058	7.0224	0.0600	1.7743	1.4606	2.2973
Bohou	3.6987	7.3193	9.3784	10.3980	11.7225	12.1966	4.4916	4.5596	6.0122	6.0632
Davié	6.0769	9.8241	0.8666	5.9560	3.9881	6.2169	1.4549	2.6252	0.0657	2.1862
Hihéatro	3.2197	8.7229	2.6454	6.8210	5.1035	7.2630	1.8652	3.1943	0.3446	2.6160
Kara-dongoyo	1.0615	11.6092	5.3502	11.1133	8.1444	11.8600	1.9490	6.3530	3.4696	6.9714
Kara-marché	5.1302	9.9610	11.2541	13.1082	13.8714	14.9601	7.2688	7.8756	8.7894	9.2975
Kélégougan	3.5657	6.7746	3.2585	5.1128	6.3065	6.9083	0.6946	0.7365	2.2152	2.2287
Kolondè	5.1498	10.1292	1.6390	7.0944	4.6652	7.4303	0.9967	3.3598	0.5239	3.2510
Kpatégan	13.5688	17.0636	6.2088	10.4505	2.8312	7.9164	7.6850	9.0637	6.1644	7.8161
Lamatessi	14.1247	17.1193	6.6061	10.2568	3.1310	7.4159	7.7605	8.7950	6.2399	7.4875
Lomé-centre	13.5172	14.6243	18.6335	19.0108	20.6309	20.8009	12.6028	12.6031	14.1234	14.1237
Nukafu	4.9227	7.8520	11.0431	11.8508	13.6582	14.0241	7.0506	7.0771	8.5712	8.5930
Passoua	1.4601	10.0419	5.9504	10.0548	9.3589	11.6748	4.5764	6.3417	6.0970	7.5131
Pya	5.7833	11.6234	1.1367	8.3359	4.2436	8.3023	1.2327	4.7185	0.2879	4.5637
Sada	8.7505	11.1070	1.2166	5.1585	2.2680	4.5019	2.3398	2.6783	0.8192	1.5393
Sagbadéi	10.2800	13.1418	2.8791	6.9795	0.5237	5.2592	4.2723	5.0250	2.7517	3.8171
Sarakawa	10.3421	13.3453	2.6963	7.1355	0.8571	5.5487	3.5924	4.6145	2.0718	3.5610
Sombou	4.5602	8.2300	2.1135	5.4527	5.0689	6.3981	0.7558	1.5235	0.7648	1.5280
Télessou	4.6802	7.8992	10.5059	11.4480	12.9397	13.3869	5.9153	5.9779	7.4359	7.4858
Témédja	12.5721	17.5555	6.1298	11.9386	3.2061	9.6716	9.1037	11.2144	7.5831	10.0194
Tomdè	8.3533	12.6785	1.6934	7.9013	1.2536	6.7163	4.5906	6.1043	3.0700	5.0609
Totsi	3.2299	7.4718	8.7737	10.0602	11.0341	11.6721	3.6109	3.8173	5.1315	5.2787
Zanguéra-péage	2.1337	7.7334	4.5349	7.2076	7.4873	8.7231	1.6554	2.5091	3.1760	3.6935
Zanguéra 2	3.5475	7.1344	3.4159	5.5462	6.5495	7.3113	1.1345	1.3196	2.6551	2.7393
Zongo	1.5025	5.6340	4.6220	5.8664	7.2395	7.6574	0.6378	0.6422	2.1584	2.1597

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