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Propagation model optimization based on Artificial Bee Colony algorithm: Application to Yaoundé town, Cameroon.

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Abstract:
Propagation models are keys for network planning and optimization. Initially used in majority for mobile radio networks, the emergence of new concepts like Digital Terrestrial Television, IoT with broad deployment for different use cases like smart grid, intelligent metering of electricity, gas and water; propagation model optimization becomes essential for an efficient network deployment in different kinds of environment namely rural, suburban and urban. In this paper we propose a new method for propagation model optimization based on Artificial Bee Colony optimization (ABC Optimization) which can be very helpful for mobile network and IoT transport network deployment like LoRaWAN, LTE-M and NB-IoT networks.
For this purpose, radio measurements were made on an existing CDMA2000 1X-EVDO network through drive test on 800MHz frequency band and by using K factors propagation model with 6 coefficients, combined with appropriate ABC optimization algorithm, a new propagation model which fits the measurement data can be deducted. Calculating the root mean squared error (RMSE) between the actual measurement data and radio data from the prediction model developed allows the validation of the results. A comparative study is made between the value of the RMSE obtained by the new model and those obtained by the standard model of OKUMURA HATA. We can conclude that the new model is better and more accurate for the local environment than that of OKUMURA HATA. The proposed solution and method can be used by researchers everywhere for propagation model optimization or determination and the newly obtained model can be used for optimal network planning and deployment.
Keywords: ***Drive test, Artificial Bee Colony optimization, propagation models, root mean square error.***

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I. Introduction

A propagation model suitable for a given environment is an essential element in the planning and optimization of a mobile network. With the development of Digital Terrestrial Television, mobile network deployment based on 4GLTE in FDD and TDD mode, and IoT based transport network like LoRaWAN, NB-IoT and LTE-M, accurate and appropriate propagation model that really fits the environment is important for optimal coverage and also capital expenditure (CAPEX) reduction on a new deployment project or an expansion one. To determine the characteristics of a radio propagation channel, field tests have to be done and based on that, calibration procedure can be made using an existing propagation model like Okumura-Hata or COST231-Hata to obtain an optimal propagation model that accurately reflects the characteristics of radio propagation in the given environment.

Many authors have worked on propagation model optimization, for example Deussom and Tonye [1] worked on “New Approach for Determination of Propagation Models Adapted To an Environment Based On Genetic Algorithms: Application to the City Of Yaoundé, Cameroon”; R. Mardeni and K. F. Kwan [2] presented “Optimization of Hata prediction model in suburban area in Malaysia”; Chhaya Dalela, and al [3] who worked on “tuning of Cost231 Hata model for radio wave propagation prediction”; Medeisis and Kajackas [4] presented "the tuned Okumura Hata model in urban and rural areas at Lituania at 160, 450, 900 and 1800 MHz bands; Deussom E. and Tonye E. [5] worked on " Optimization of Okumura Hata Model in 800MHz based on Newton Second Order algorithm. Case of Yaoundé, Cameroon”, MingjingYang et al. [6] in China have presented "A Linear Least Square Method of Propagation Model Tuning for 3G Radio Network Planning", Deussom E. and Tonye E [7] have also worked on “New Propagation Model Optimization Approach Based on Particles Swarm Optimization Algorithm”.

The present paper is a extension of the work cited on references [1] ,[5] and [7], we propose an optimization approach based on Artificial Bee Colony optimization (ABC Optimization), which is based on a proposed K factors model with 6 coefficients [1] [5] and [7], the ABC optimization is capable of optimizing more than 2 coefficients (up to 6 coefficients) in the K factors model compared to other method like linear regression mostly used by authors worldwide which is limited on the optimization of only 2 parameters. In addition ABC can output not only one solution, but a set of possible solutions, among them the best one is selected as final one. Furthermore the solution has more diversity compare to that of linear regression method. This article will be articulated as follows: in section 2, the background, experimental details and the methodology will be presented, followed in section 3 by the result obtain after the implementation. In section 4 we will present the discussion of the result and finally we will have a conclusion in section 5.

II. Material And Methods

2.1 Propagation environment.

For this study, drive test was done in the city of Yaoundé, capital of Cameroon on a CDMA 2000 1X-EVDO network working on the following frequencies 870MHz-880MHz for downlink and 825MHz-835MHz for uplink. We can notice that this frequency can be used for LTE800MHz and is closed to LoRaWAN frequency adopted in France and European Union. To do this, we divided the city into 3 categories namely: downtown Yaoundé, the extended downtown Yaoundé) and finally Yaoundé Outskirts. We have the table below which shows the categories with the concerned BTS:

Table 1: Types of environment

Categories	A	B	C
Urban characteristics	Dense urban	Urban	Outskirts
Concerned BTS	Ministry PTT	Hotel du plateau	Ngousso Eleveur

2.2 Equipments description

2.2.1 Simplified description of BTS used.

BTS that were used for the drive tests are CDMA2000 ones with 2 types namely: BTS3606 and DBS3900 [9]. The following table shows the specifications of the BTS

Table 2: BTS characteristics

	BTS3606	DBS3900
BTS types	Indoor BTS with 3 sectors	Distributed BTS (Outdoor) with 3 sectors
Downlink/ Uplink frequency	(869 MHz - 894 MHz) /(824 MHz - 849 MHz)	
BTS Total power (dBm)	43 dBm	43 dBm

The BTS engineering parameters are presented in the table below:

Table 3: BTS engineering parameters

BTS information									
BTS Type	**BTS name**	**Latitude (degree)**	**Longitude (degree)**	**BTS Altitude (m)**	**Antenna height**	**Mean elevation**	**Antenna effective height**	**Antenna's Gain（dBi）**	**7/8 Feeder Cable(m)**
3606	MinistryPTT_800	3,86587	11,5125	749	40	741,82	47,18	15,5	45
3900	Ngousso-Eleveur	3,90097	11,5613	716	25	712,05	28,95	17	0
3900	Hotel du plateau	3,87946	11,5503	773	27	753,96	46,04	17	0

2.2.2 Others equipments parameters.

In order to perform the drive tests, we used a Toyota Prado VX vehicle, an ACER ASPIRE laptop, drive test software namely Pilot pioneer of Dingli communication V6.0, an LG CDMA mobile terminal, a GPS terminal, a DC/AC converter to power the PC during the measurement. The figure below shows the vehicle collection kit.

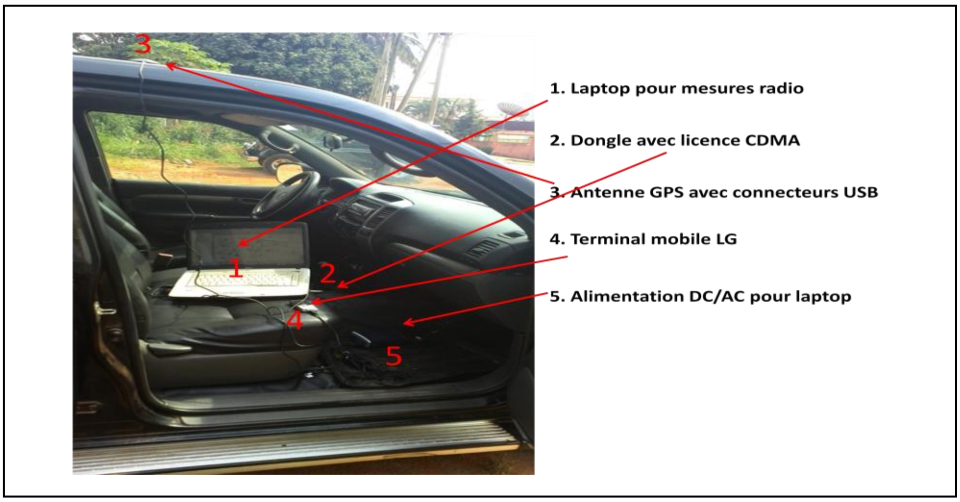

Figure 1: Drive test measurement kit installed on vehicle.

The drive tests done in the area A, B, and C gave the following results.

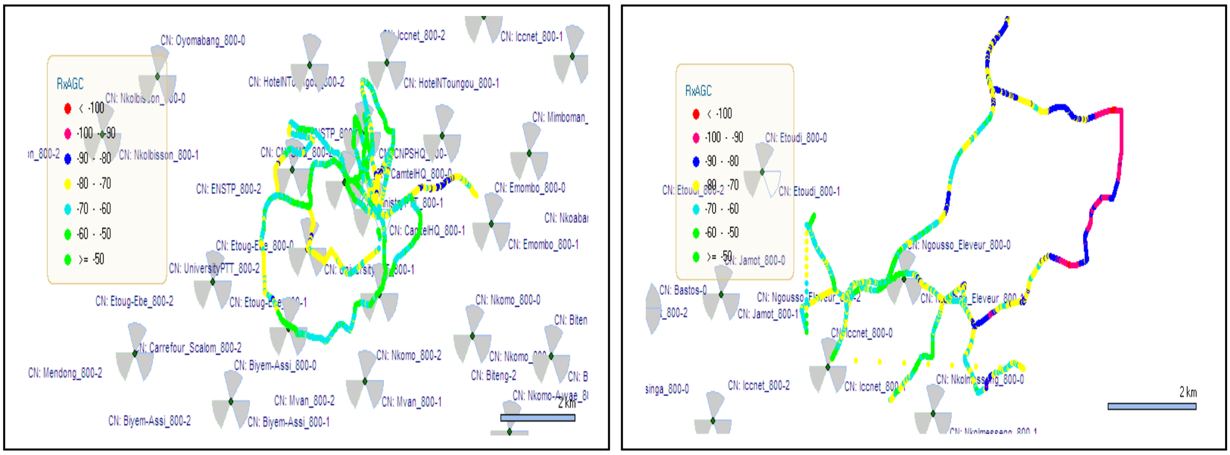

Figure 2: Drive test in centre town (A left side image) and in Ngousso eleveur (B right side image)

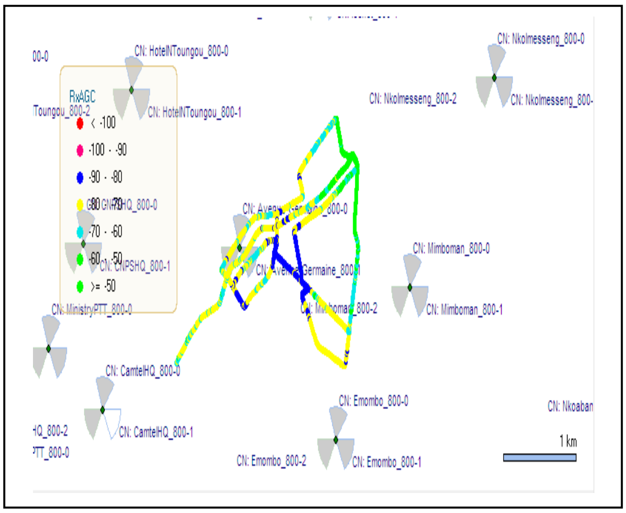

Figure 3: Drive test in Essos

2.3 Methodology

2.3.1 *K factors propagation model [8]*

There are many propagation models presented in scientific literature, but this modeling is based on K factors propagation model.

The General form of the K factors model is given by the following equation:

$$L_p = K_1 + K_2 \log(d) + K_3 * h_m + K_4 * \log(h_m) + K_5 * \log(h_b) + K_6 * \log(h_b) \log(d) + K_{7diffn} + K_{clutter} \quad \textbf{(1)}$$

K_1 constant related to the frequency, K_2 constant of attenuation of the distance or propagation exponent, K_3 and K_4 are correction factors of mobile station height; K_5 and K_6 are correction factors of BTS height, K_7 is the diffraction factor, and $K_{clutter}$ correction factor due to clutter type.

The K parameter values vary according to the type of the landscape and the characteristics of the propagation of the city environment; the following table gives values of K for a medium-sized town.

Eq. (1) could also be written in the following form:

$$\mathbf{L_p = (K_1 + K_{7diffn} + K_{clutter}) + K_2 \log(d) + K_3 * h_m + K_4 * \log(h_m) + K_5 * \log(h_b) + K_6 \log(h_b) \log(d)}$$

Assuming $K_1' = (K_1 + K_{7diffn} + K_{clutter})$, Eq. (1) gets the form below:

$$\mathbf{L_p = K_1 + K_2 \log(d) + K_3 * h_m + K_4 * \log(h_m) + K_5 * \log(h_b) + K_6 \log(h_b) \log(d)} \quad \textbf{(2)}$$

Equation (2) above can be written in matrix form as follows:

$$\boldsymbol{L = [K_1\ K_2\ K_3 K_4\ K_5\ K_6]} * \begin{bmatrix} \mathbf{1} \\ \mathbf{\log}(\boldsymbol{d}) \\ \boldsymbol{H_m} \\ \mathbf{\log}(\boldsymbol{H_m}) \\ \mathbf{\log}(\boldsymbol{H_{eff}}) \\ \mathbf{\log}(\boldsymbol{H_{eff}}) * \mathbf{\log}(\boldsymbol{d}) \end{bmatrix} \quad \textbf{(3)}$$

In the above equation (3) only the vector K=$[K_1\ K_2\ K_3 K_4\ K_5\ K_6]$ **(4)** is variable depending on the values of, $i \,\boldsymbol{\epsilon}\{\mathbf{1},\mathbf{2},\mathbf{3},\mathbf{4},\mathbf{5},\mathbf{6}\}$ and j an integer.

Let:

$$\boldsymbol{M} = \begin{bmatrix} \mathbf{1} \\ \mathbf{\log}(\boldsymbol{d}) \\ \boldsymbol{H_m} \\ \mathbf{\log}(\boldsymbol{H_m}) \\ \mathbf{\log}\boldsymbol{H_{eff}}) \\ \mathbf{\log}(\boldsymbol{H_{eff}}) * \mathbf{\log}(\boldsymbol{d}) \end{bmatrix}, \quad \textbf{(5)}$$

Therefore L can be written in the form $L = K * M$ **(6)**; with M a constant vector for a given distance d. If d varies for different measurement points, vector M becomes a $M_i$vector for various measures at different distances d_i .

a) Evaluation function.

Here, we have to minimize the Euclidean distance between the measured values of the propagation loss and those predicted by the propagation model. Let $L = \{L_j\}_{j=1:T}$ the set of measured values; where T represents the total number of measurement points of L. K^j is a possible solution vector to our optimization problem and M_i the column vector defined by (5). The evaluation function [1] [5] [7] of each variable K^j will be:

$$\boldsymbol{f_{cout} = min\left\{\frac{1}{T}\sum_{i=1}^{T}(L_i - (K^j * M_i))^2\right\}} \quad \text{and } \mathbf{RMSE} = \sqrt{\boldsymbol{f_{cout}}} \quad [1][7] \quad \textbf{(6)}$$

2.3.2 Propagation model optimization based on ABC algorithm

a) Determination flowchart

The flowchart below represents the determination of the propagation model using ABC algorithm.

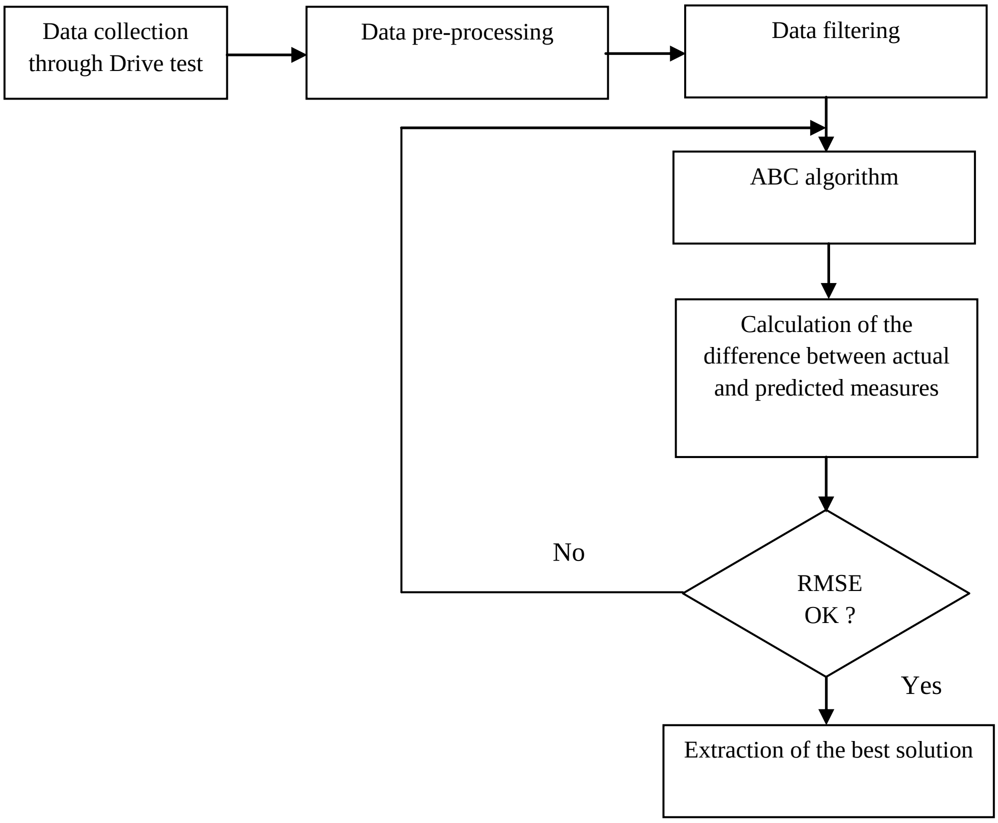

Figure 4: Algorithm implementation flowchart

In this chart, data filtering is made according to the criteria of distance and signal strength received:

Table 5: filtering criteria. [10]

Minimum distance (m)	100
Maximum distance (m)	10 000
Minimum received power (dBm)	-110
Maximum received power (dBm)	-40

The idea behind this is to show that using k factors equation with 6 coefficients, drive test data and an efficient ABC algorithm, we can get a propagation model for a given frequency. The following picture presents an illustration of the idea.

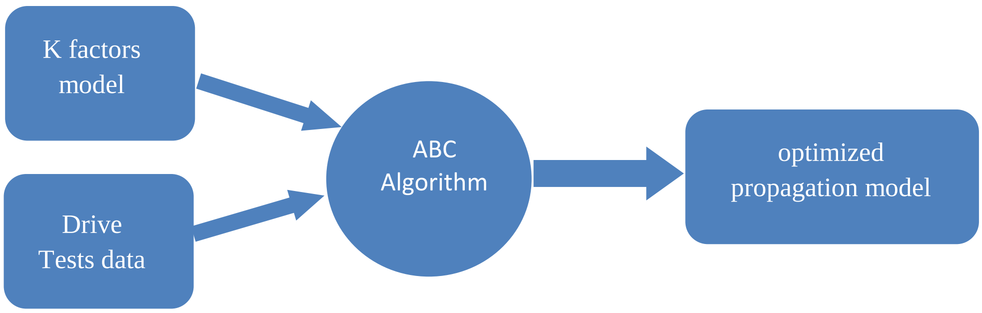

Figure 5: implementation bloc diagram

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2.3.2 ABC algorithm presentation and modeling

In the ABC model, the colony consists of three groups of bees [11]: employed bees, onlookers and scouts. A candidate solution to the optimization problem is represented by a food source. Each food source has an amount of nectar that characterizes its quality (fitness). In this algorithm, each group of bees is not representing a solution like other population algorithm (for example Genetic algorithms presents in [1] and particles swarm optimization algorithm presented in [7]), but a set of iterations. Each group of iterations corresponds to the flight of one of the three types of bees: employed bees, onlookers and scouts.

The employed go around the food sources to find a better source than the one visited. They then share the quality of the source with the onlookers; these last mainly focus on better food sources. When a food source has been sufficiently explored, it is abandoned and the scouts randomly go to search for a new source.

a) Summary of the algorithm

The number of employed and onlookers bees corresponds to the number of food sources. There is usually a scout bee. A food source is a vector of dimension D, D being the dimension of the problem, for this problem, D=6 as the vector K is a 6 dimension vector. The number of food sources (SN) is a parameter of the algorithm. Now we will presents each type of flight, for employed, onlookers and scouts.

Flight of employed bees

Each worker bee produces a new solution in the vicinity of an existing food source, according to **(7)**. For the i^{th} bee ($i \in \{1, ..., SN\}$) and $j \in \{1, 2,. . . , D\}$, φ_{ij} is a random real, uniformly distributed in the interval [-1; 1] and $k \in \{1,. . . , SN\}$, a randomly chosen solution ($k \neq i$). The new food source is defined by:

$$N_j^i = K_j^i + \varphi_{ij}(K_j^i - K_j^k) \text{ , [13]}$$

(7)

An improvement of this production of new source is proposed by [12] [13] with following new equation

$$N_j^i = K_j^i + \varphi_{ij}\left(K_j^i - K_j^k\right) + \theta_{ij}(K_j^{best} - K_j^i),$$ **k** # j, with θ_{ij} a random number belonging to [0; 1.5].

(8)

If the new food source N^i thus produced has better fitness than K^i, it replaces it. Otherwise, a counter for the number of unsuccessful visits is incremented.

Flight of onlookers' bee

This series of iterations is similar to the previous one, except that an onlooker bee visited a promising food source, which has a good amount of nectar. This information is shared by the employed by using the fitness value defined by **(9)** where f_{cout} is defined by **(6)** presented above. $f_{fit}(K^i) = \frac{1}{f_{cout}(K^i)+1}$,

(9)

This makes it possible to calculate a potential attractiveness in the form of probability of selection.

$$P_i = \frac{fit(K^i)}{\sum_{k=1}^{SN} fit(K^k)}$$

(10)

For an onlooker bee iteration, a new solution N^i is generated in the same way like the one of an employed bee.

Flight of scout bee

During these two previous phases, when a new solution N^i generated from a solution K^i does not improve the latter, a number of visits NbVisits(i) counter is incremented for solution K^i. When this counter reaches a limit value, the solution is abandoned and replaced by a new solution produced according to (8).

The advantage of this algorithm is that it has only a few parameters: the number of food sources, the number of exploratory bees and the maximum number of unimproved visits to a food source. In the next paragraph, we will present the global form of the algorithm and later we will adapt it in our precise problem.

b) Algorithm presentation.

Initialization

First, the algorithm initializes a population of SN individuals, as described in equation (8), Xmin and Xmax are the vectors of the minimum and maximum values of each dimension of the problem.

$i \in \{1, \ldots, SN\}, j \in \{1, \ldots, D\}$ *and* $K_j^i = K_{\min j} + rand[0,1](K_{\max j} - K_{\min j})$

Each source of food is associated with a quantity of nectar defining an attractiveness, fitness. This value is calculated using equation (9), where fit is the objective function.

$\boldsymbol{f_{fit}(K^i) = \frac{1}{f_{cout}(K^i)+1}}$ where $f(K^i)$ is the evaluation function of the a food source K^i.

Variable identification.

The food source will be the vector $K = [K_1\ K_2\ K_3\ K_4\ K_5\ K_6]$ and D=6 is the variable dimension, and the variable j will belongs to the set {1,2,3,4,5,6}, and finally $K^i = [K_1^i\ K_2^i\ K_3^i\ K_4^i\ K_5^i\ K_6^i]$

Global algorithm (Minimization)

1. **Initialization of the food source and fitness.**
2. **While** "Ending condition not satisfied" **do**

```
//employed flight
        For i=1 to employednumber do
                New food source generation N^i according to Equation (8)
                If fit(N^i) > fit(K^i) then
                K^i ← N^i
                End If
                Else Nbvisites(i) ← Nbvisites(i)+1
                End
        End for
        Updating of the food quality according to Equation (8)
        //Onlookers flight
        i←1
        while i≤ Nbofonlookers do
                k←rand(SN)
                if rand(0,1)< Pk (See Equation (8)) then
                        generation of a new solution N^k according to Equation (8)
                        if fit(N^k) > fit(K^k) then
                        K^k ← N^k
                        End if
                        Else
                                Nbvisites(k) ← Nbvisites(k)+1
                        End else
                        i = i + 1
                End if
      End While
End while
```

The following table presents an example of propagation model as food source, there are corresponding to Okumura Hata model, K factors and free space above when the frequency is 870MHz.

Table 5: Propagation models into the K factors form.

Propagation model	K1	K2	K3	K4	K5	K6
Okumura Hata	146,56	44.9	0	0	-13.82	-6,55
Free space	91.28	20	0	0	0	0
K factors	149	44.9	-2.49	0	-13.82	-6,55

These 3 food sources will be part of the possible food sources. Now we need to present how to generate the other food sources to have the full food sources for the program to run.

We have the following criteria for generation of the different parameters.

a) Generation of K_4^j

The parameters K_4^j is a micro adjustment parameter whose value is between 0 and 1, then: $\mathbf{0 \leq K_4^j \leq 1.}$ We have the following algorithm:

For j = 4 :SN do
K_4^j=rand (1)
End for

b) Generation of K_1^j

We are searching for K_1^j between the values of the parameters K1 of free space and OKUMURA-HATA model. Let K_{1el} and K_{1ok} respectively the parameters K1 for of free space and OKUMURA-HATA model, then we will have: $K_{1el} \leq K_1^j \leq K_{1ok}$. We will generate random values between K_{1el} and K_{1ok}.
All this allows us to have the following algorithm:

For j = 4 : SN do
$K_1^j = K_{1el} + (K_{1ok} - K_{1el}) * rand(1)$
End for

c) Generation of K_6^j

We will search this parameter between the values -6.55 and 0, what justifies this choice is that this setting is worth these respective values for Okumura Hata and free space loss model. We will therefore have the algorithm below:

For j = 4 :SN do
*K_6^j=-6.55*rand (1)*
End for

d) Generation of parameter K_2^j

The global adjustment parameter K2 should follow the criteria below:
$K_{2el} \leq K_2^j + K_6^j \log(H_b) \leq K_{2ok}$, in fact $K_2^j + K_6^j \log(H_b)$ is the distance attenuation factor and for that should be comprise between K_{2el} and K_{2ok}. $K_{2el} = 20$, and $K_{2ok} = 44.9 - 6.55\log(H_b)$, now in urban areas, the minimum possible height for a base station is 20 meters, this minimum value of Hb, allows us to obtain the maximum value of $K_{2ok} = 36.8$. This allows us to write that:

$$20 - K_6^j \log(H_b) \leq K_2^j \leq 36.8 - K_6^j \log(H_b)$$

We can deduce the following algorithm:

For j = 4 : SN do
$K_2^j = 20 - K_6^j \log(H_b) + (36.8 - 20) * \mathrm{rand}(1)$
End for

e) Generation of K_5^j

This parameter is negative and is in between -13.82 and 0. (-13.82 is the parameter value for K factor and Okumura Hata model**),** we can then deduce the algorithm below:

For j = 4 : SN do
*K_5^j=-13.82+13.82*rand (1)*
End for

f) Generation of K_3^j

Finally the parameter K_3^j will vary between -2.49 and 0 for 800MHz frequency band, value defined by K factor propagation model, from which we derive the algorithm below:

For j = 4: SN do
*K_3^j=-2 .49+2.49*rand (1)*
End for

The overall starting family generation algorithm is therefore with $F(i,j) = K_i^j$;

Begin
F(1) = Kok ;
F(2)= Kel ;
F(3)= Kkfac ;
For j = 4 : SN do
F (j, 4) = rand (1);
$F(j,1) = K_{1el} + (K_{1ok} - K_{1el}) * rand(1)$;
*F(j,6)=-6.55*rand (1);*
$F(j,2) = 20 - K_6^j \, log(H_b) + (36.8 - 20) * rand(1)$

*F (j, 5) =-13.82+13.82*rand (1)*
*F (j, 3) =-2 .49+2.49*rand (1)*
End for
End

III. Results

After the implementation of ABC algorithm on the radio measurement data obtained in Yaoundé through drive tests and by setting the parameters as follows:
NS= 100; the maximum number of iterations is set to 50;
The model will be seen as accurate if the RMSE between drive test data and the predicted ones is less than 8 dB; (RMSE < 8dB) [14]. We have the following results per area.

3.1 Area 1: Downtown Yaoundé

The following table presents the results and the figure presents the graph of Drive test data, new propagation model as optimized food source in red color, drive test data in black color, Okumura Hata path loss as a potential food source in blue, free space loss as another food source in yellow and linear regression result in green.

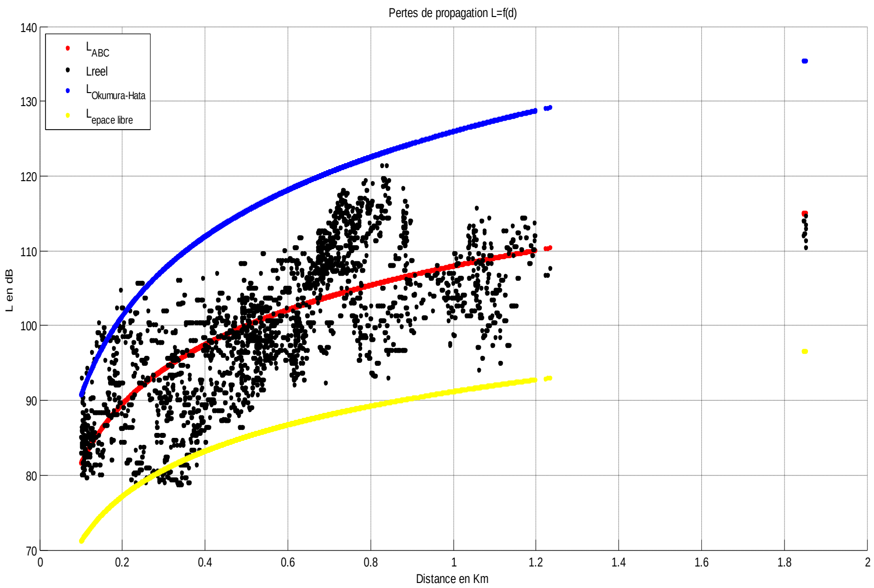

Figure 6: Actual data in Centre town VS predicted measurements.

The table below gives the results of K factors values for Area A.

Table 6: Results from the city center.

Zone	Methode	K1	K2	K3	K4	K5	K6	**RMSE**	**RMSE(OK)**
A	ABC	54.90	34.76	-2.49	0	-13.82	-5.26	**6.71**	14.55

Note that we have a RMSE =6.71 and less than the threshold of 8dB which confirms the reliability of the result and better than **RMSE calculate with Okumura Hata model (RMSE(OK)).**
Figure 7 shows the evolution of the cost function per iteration. After 8 ieterations we have the convergence of the algorithm.

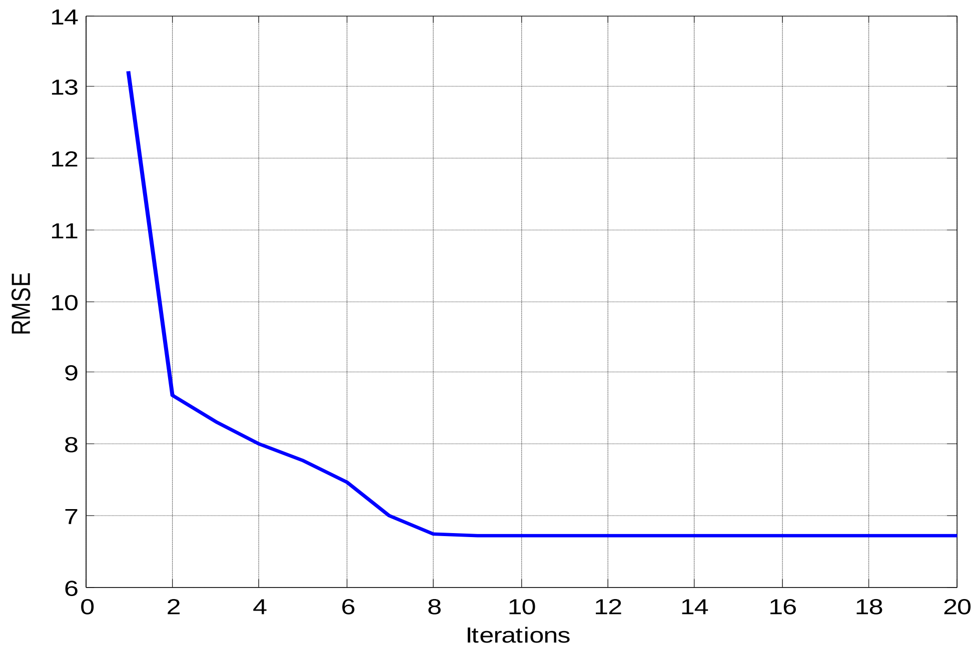

Figure 7: Evolution of the Cost function with respect to the number of iterations.

3.2 Area 2: Essos area (Another part of the town).

The table 7 presents the results obtains in the area of Essos after implementing the ABC algorithm on Drive tests data.

Table 7: Results from the city center.

Zone	Methode	K1	K2	K3	K4	K5	K6	**RMSE**	**RMSE(OK)**
B	ABC	63.9861	38.8889	-2.4900	0	-13.8200	63.9861	7.3907	13.59

The figure 8 and 9 presents respectively the results obtained.

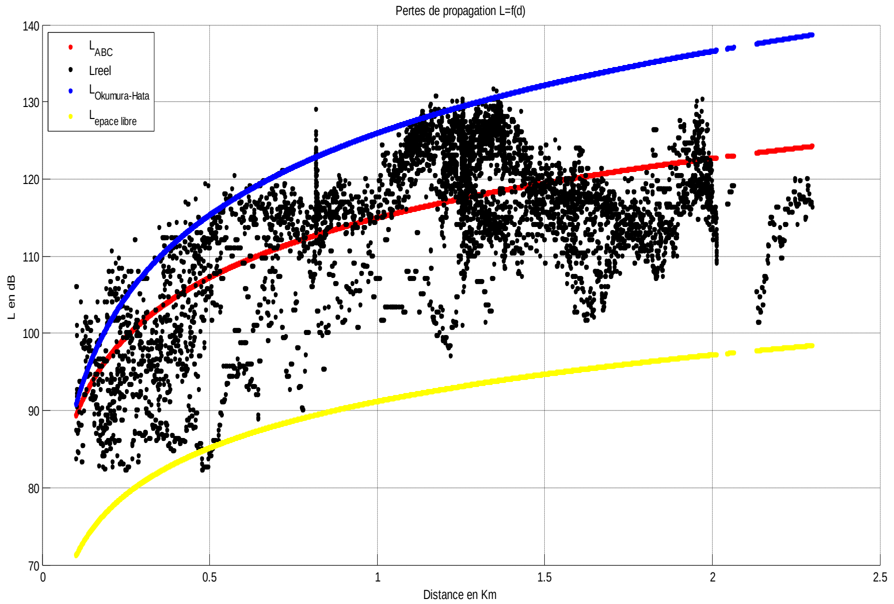

Figure 8: Actual data in Essos VS predicted measurements.

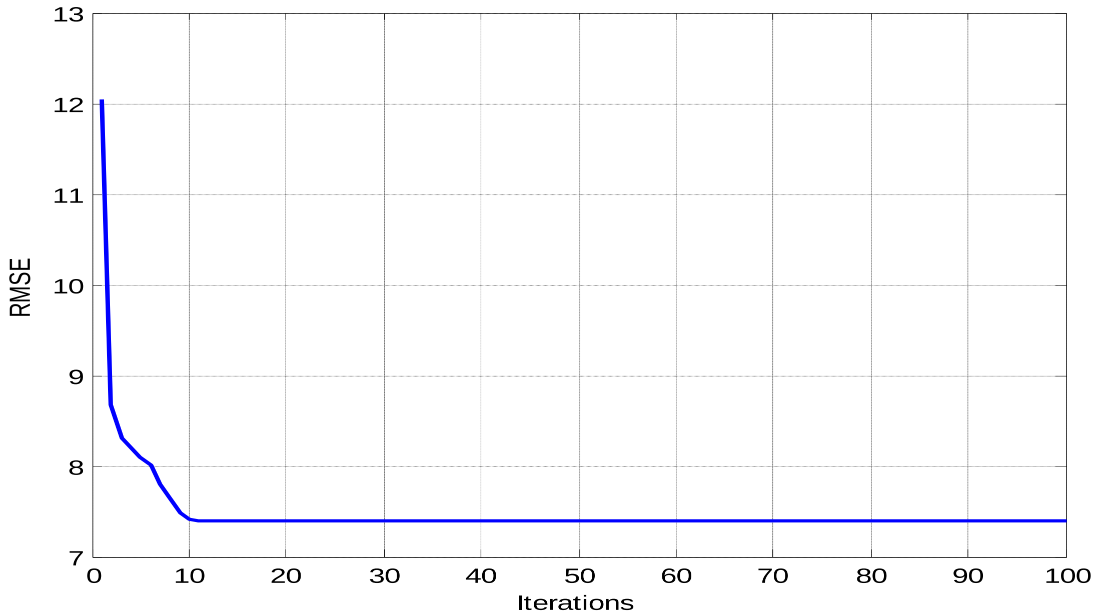

Figure 9: Evolution of the Cost function with respect to the number of iterations in Essos Area

3.3 Area 3: Ngousso area (Another part of the town).
We got the following table as results.

Table 8: Results from the city center.

Zone	Methode	K1	K2	K3	K4	K5	K6	RMSE	RMSE(OK)
C	ABC	76.238	32.74	-4.97	0.015	-13.82	-6.55	**7.8927**	16.51

We also have the following figures representing the propagation models and drive tests data and the evolution of the cost functions with respect to the number of iterations.

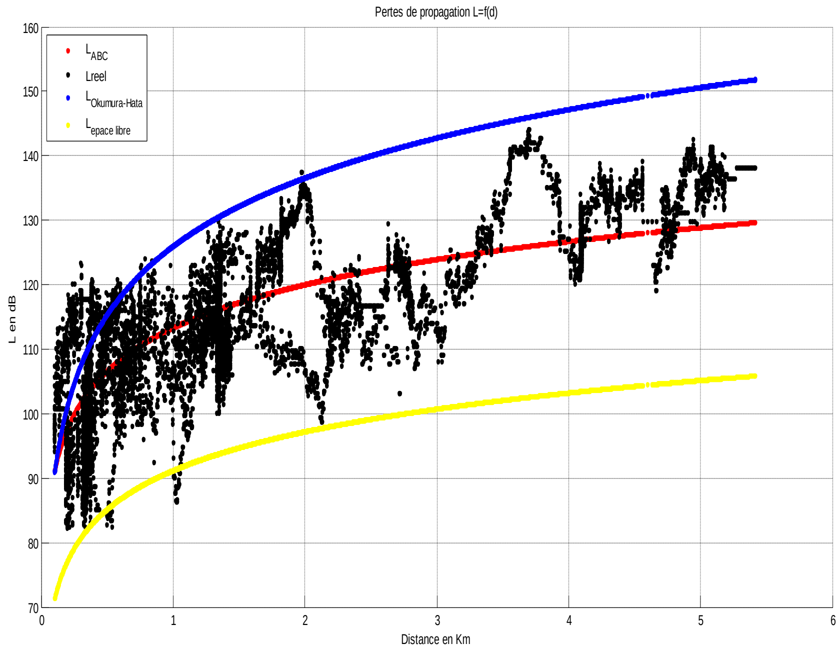

Figure 10: Actual data in Ngouso-Eleveur VS predicted measurements.

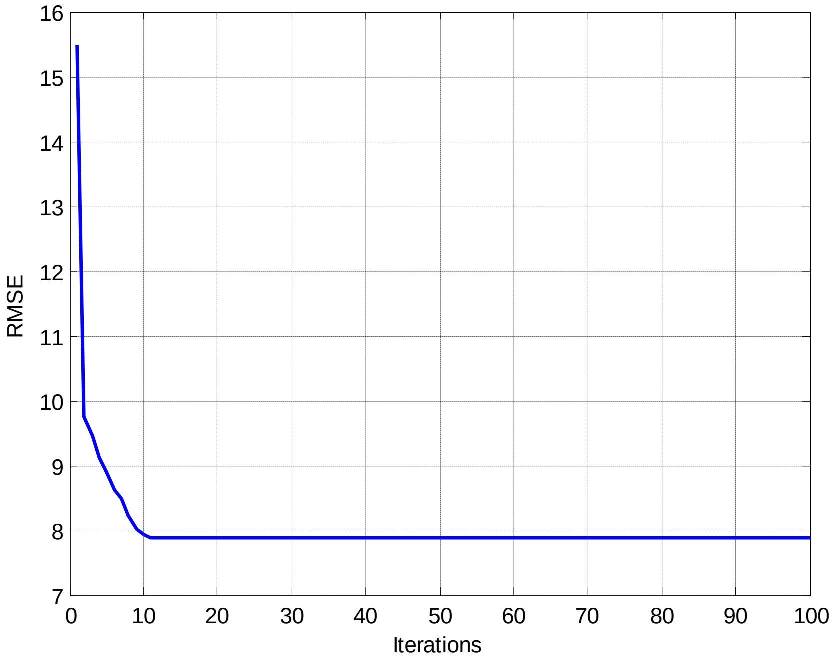

Figure 11: Evolution of the Cost function with respect to the number of iterations in Ngousso Area

IV. Discussion

After the implementation of the ABC algorithm using the drive tests data from different areas in Yaoundé, we were able to output a new propagation model derived from K factors model with 6 coefficients with a RMSE which is less than 8dB. This means that the new model is (accurate) according to [14].

During the implementation and at different iterations, some parameter values went (go) out of their specific range and later came (come) back in range after further iterations). Also, in all the cases we got a fast convergence of the algorithm after less than 12 iterations while running the algorithm for sometimes 100 iterations.

Another precision is, when running the algorithm several times you can obtain results (not exactly the same) but with the same precision (same value of RMSE). This can be explained by the fact the function **rand()** outputs values randomly within the specified range, we think it is a drawback for this algorithm.

Nevertheless, we got accurate results when running the ABC algorithm.

V. Conclusion

This paper presents a new method to determine a propagation model with respect to a given environment.

The method described is original and could very well be used to design or calibrate propagation models. As advantage, we can get a set of solution after using ABC algorithm and amongst them we select the best one (with minimum RMSE). Nevertheless we found a very fast convergence of the algorithm while we were expecting it to happen after a big number of iterations. Practical measurements done in the city of Yaoundé gave us very good results with an RMSE less than 8dB for most of the selected areas in the city; compared to Okumura Hata RMSE obtained, the new model gives a better result .This means it is accurate for network planning and deployment.

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