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# COST 231-Hata Propagation Model Optimization in 1800 MHz Band Based on Magnetic Optimization Algorithm: Application to the City of Limbé

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## Abstract

Network planning is essential for the construction and the development of wireless networks. The network planning cannot be possible without an appropriate propagation model which in fact is its foundation. Initially used mainly for mobile radio networks, the optimization of propagation model is becoming essential for efficient deployment of the network in different types of environment, namely rural, suburban and urban especially with the emergence of concepts such as digital terrestrial television, smart cities, Internet of Things (IoT) with wide deployment for different use cases such as smart grid, smart metering of electricity, gas and water. In this paper we use an optimization algorithm that is inspired by the principles of magnetic field theory namely Magnetic Optimization Algorithm (MOA) to tune COST231-Hata propagation model. The dataset used is the result of drive tests carry out on field in the town of Limbe in Cameroon. We take into account the standard K-factor model and then use the MOA algorithm in order to set up a propagation model adapted to the physical environment of a town. The town of Limbe is used as an implementation case, but the proposed method can be used everywhere. The calculation of the root mean square error (RMSE) between the real data from the radio measurements and the prediction data obtained after the implementation of MOA allows the validation of the results. A comparative study between the value of the RMSE obtained by the new model and those obtained by the optimization using linear regression, by the standard COST231-Hata models, and the free space model is also done, this allows us to conclude that the new model obtained using MOA for the city of Limbe is better and more representative of this local environment than the standard COST231-Hata model. The new model obtained can be used for radio planning in the city of Limbé in Cameroon.

## Keywords

Radio Measurements, Root Mean Square Error, Magnetic Optimization Algorithm

## 1. Introduction

A propagation model adapted to a given environment is an essential element for the planning of a mobile network. The key issues in radio planning are: coverage, capacity and quality of service. In order to provide users with access to the various mobile services, particular emphasis should be placed on the dimensioning of the radio coverage. Propagation models are widely used in network planning, in particular for feasibility studies and initial network deployment, or for network extensions, especially in new metropolitan areas. In order to determine the characteristics of the radio propagation channel, tests of real propagation models and calibration of existing models are necessary to obtain a propagation model that accurately reflects the radio propagation characteristics in a given environment. Many researchers have worked and proposed numerous algorithms with inspiration from nature for solving various optimization problems. Some of the most popular are Genetic Algorithm (GA) [1], Particle Swarm Optimization (PSO) [2], and Artificial Bee Colony (ABC) [3]. These algorithms can perform well in many problems either discrete or continuous ones with different advantages and disadvantages compared to each other. A physics-inspired metaheuristic optimization algorithm based on Magnetic Optimization Algorithm (MOA) whose possible solutions are magnetic particles scattered in the search space was published in 2008 [4]. It is gradually being used to solve problems in various fields. As MOA is a population based algorithm, through this work we also test and evaluate its capability to solve the propagation model optimization problem by using drive tests. The objective of this study is to integrate the use of the MOA algorithm in the resolution of a real problem in the field of telecommunications like propagation model optimization. This work is not the first to focus on the optimization of propagation models. Many authors from various backgrounds have proposed different approaches to optimize propagation model. R. Mardeni and K. F. Kwan [5] presented "Optimization of Hata prediction model in suburban area in Malaysia", their optimization solution is based on linear regression; Chhaya Dalela *et al.* in [6] worked on "tuning of Cost231 Hata model for radio wave propagation prediction". Deussom Eric *et al.* have proposed many methods for propagation model optimization by using particle swarm optimization [7], artificial bee colony algorithm [8], Social Spider Algorithm [9], genetic algorithm [10]

[11], Newton second order optimization [12], linear regression [13], Ion Motion Optimization Algorithm [14] and others methods. In our study, we use data collected in the LTE network working in 1800 MHz frequency band of a mobile the operator in Cameroon. To do this, we use 3 eNodeBs located in Limbe and distributed on both sides of the city. We use Magnetic Optimization Algorithm to determine an appropriate propagation model adapted to the city of Limbe.

## 2. Experimental Details

### 2.1. Propagation Environment

The drive tests were carried out in the city of Limbé, a seaside town in the southwest region of Cameroon. We used the existing LTE network to carry out radio measurements in the city. To do this, we subdivided the city into two categories: The city centre of Limbe, the city centre to periphery area and finally the periphery of the city. **Table 1** below shows the categories with the **eNodeBs** concerned.

### 2.2. Description of the Equipments

#### 2.2.1. Simplified Description of the eNodeB Used

The **eNodeBs** we used for our radio measurements were supplied by the equipment manufacturer HUAWEI Technologies, we used one type of **eNodeB** namely, the DBS3900 all LTE. **Table 2** below shows the technical specifications of the **eNodeBs** used.

The radio parameters of the **eNodeBs** used are shown in **Table 3** below.

- The number of subcarriers is 12 × 75 = 900;
- Antenna height = 25 m;
- Ptx = 16.45757 dBm;
- eNodeB Antenna Gain = 17.5 dBi;
- Connector loss = 1 dB;
- Interference margin = 6 dB;
- Shadow fadin margin = 10 dB;
- Incar loss (due to the car during the drive test) = 6 dB;
- Handover gain = 2 dB.

**Figure 1** presents the BTS position in the town of Limbe, we will focus on the 3 BTS mentioned above which are, Limbe_central, limbe Kie_village and Limbe_Mile4. **Figure 2** presents the drive test results obtained during the measurements operation in Limbe town. **Figure 3** presents the drive tests statistiques.

**Table 1.** Types of environment.

| Categories | A | B | |
|---|---|---|---|
| Urban | Suburban | Rural | Rural |
| Characteristic | Limbe_Central | Limbe_Mile4 | Kie_village |
| eNodeB concerned | LBE065_Limbe_Central | LBE066_Limbe_Mile4 | LBE064_Kie_village |

**Table 2.** Technical specifications of the eNodeBs used.

| Nature | DBS3900 |
|---|---|
| Type of eNodeB | Outdoor Distributed |
| Number of sectors | 3 |
| Frequency band | 1800 MHz band |
| Downward frequency | 1839.9 MHz to 1854.9 MHz |
| Rising frequency | 1744.9 MHz to 1759.9 MHz |
| Max power (single carrier) | 40 W |
| Total power of the eNodeB (dBm) | 46 dBm |

**Table 3.** Radio parameters of the eNodeBs used.

| Type of eNodeB | PCI | eNodeB name | Longitude | Latitude | CELL NAME |
|---|---|---|---|---|---|
| | 6 | LBE066_Limbe_Mile4 | 9.22514 | 4.06286 | LBE_12066_0 |
| **DBS3900** | 7 | LBE066_Limbe_Mile4 | 9.22514 | 4.06286 | LBE_12066_1 |
| | 8 | LBE066_Limbe_Mile4 | 9.22514 | 4.06286 | LBE_12066_2 |
| | 9 | LBE065_Limbe_Central | 9.20696 | 4.01194 | LBE_12065_0 |
| **DBS3900** | 10 | LBE065_Limbe_Central | 9.20696 | 4.01194 | LBE_12065_1 |
| | 11 | LBE065_Limbe_Central | 9.20696 | 4.01194 | LBE_12065_2 |
| | 54 | LBE064_Kie_village | 9.17892 | 4.01641 | LBE_12064_0 |
| **DBS3900** | 55 | LBE064_Kie_village | 9.17892 | 4.01641 | LBE_12064_1 |
| | 56 | LBE064_Kie_village | 9.17892 | 4.01641 | LBE_12064_2 |


**Figure 1.** eNodeB positions in Limbe town.

According to DT route (see **Figure 2**) around 95.63% of the town have a RSRP signal > −110 dBm. Areas with Red are areas where the coverage is weak. After this drive test, four eNodeBs where add in Limbe namely, Limbe new town, Limbe towe south, GRA limbe and Limbe mile 4 HIS.

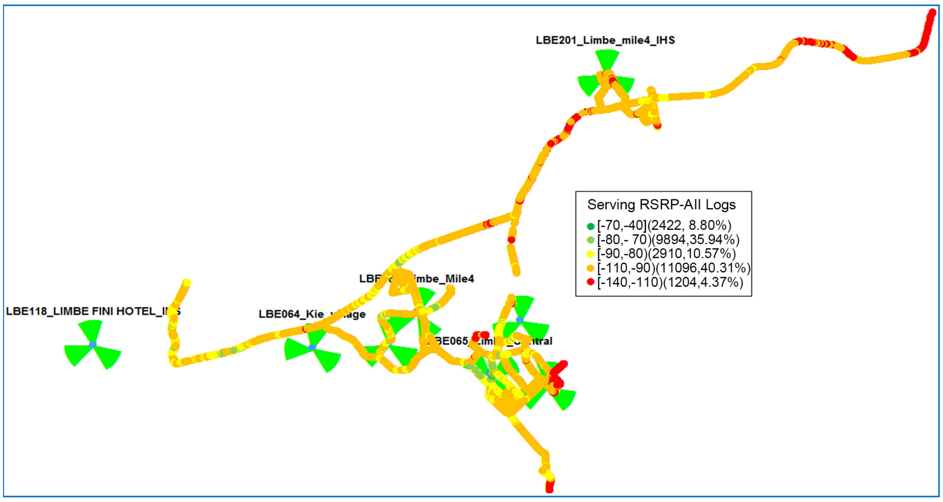


**Figure 2.** Drive test results in the town of Limbe.

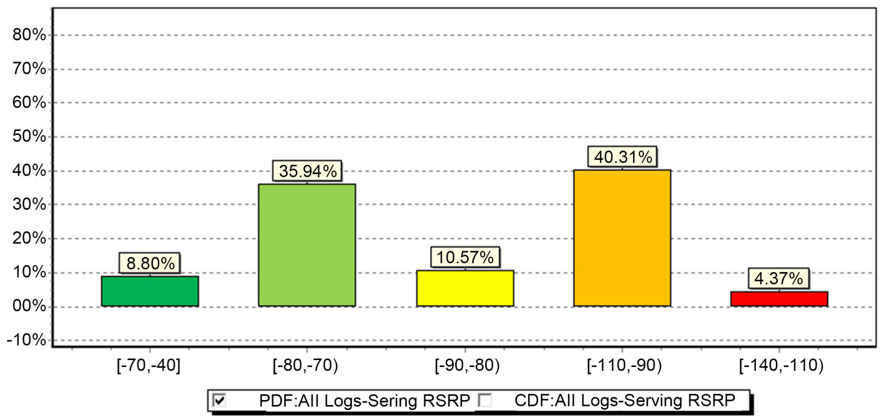


**Figure 3.** RSRP statistic in Limbe town during the drive tests.

In **Figure 3**, we can see that only 8.80% of the drive test area has a signal with excellent quality, this means that news sites should be added in this town. But is not the target of this work, we have present this to well explain the environment used for this study. We are focusing on the Received signal reference power (RSRP) values which will be used during our optimization procedure.

#### 2.2.2. Description of Other Equipment

In order to carry out the radio measurements, we used a Toyota Prado VX vehicle, an ACER ASPIRE laptop computer, a radio measurement software, namely Pilot Pionner from Dingli communication V6.0, an LG CDMA mobile terminal, a GPS terminal, a DC/AC converter to power the PC during the measurement.

## 3. Methodology

### 3.1. Propagation Model

Several propagation models exist in the scientific literature on propagation, we will present only the $K$-factor model on which we have based our work.

#### 3.1.1. *K*-Factor Propagation Model

The general form of the *K*-factor model is given by the following equation:

$$\begin{aligned}L_p &= K_1 + K_2 * \log(d) + K_3 * h_m + K_4 * \log(h_m) + K_5 * \log(h_b) \\ &+ K_6 * \log(h_b)\log(d) + K_{7\text{diffn}} + K_{\text{clutter}}\end{aligned} \tag{1}$$

The values of the *K*-parameters vary according to the type of terrain and the characteristics of the propagation environment of the cities; the table below gives values of *K* and of the clutter attenuation factor for an average city. Table 4 presents the standard value of *K* factors model.

The previous equation can be rewritten as follows:

$$\begin{aligned}L &= (K_1 + K_{7\text{diff}} + K_{\text{clutter}}) + K_2 \times \log(d) + K_3 \times h_m + K_4 \times \log(h_m) \\ &+ K_5 \times \log(h_b) + K_6 \times \log(h_b)\log(d)\end{aligned} \tag{2}$$

By taking, $K_1' = (K_1 + K_{7\text{diff}} + K_{\text{clutter}})$, the equation of the model *K* factor becomes:

$$\begin{aligned}L &= K_1 + K_2 \times \log(d) + K_3 \times h_m + K_4 \times \log(h_m) + K_5 \times \log(h_b) \\ &+ K_6 \times \log(h_b)\log(d)\end{aligned} \tag{3}$$

The previous Equation (3) can be written into two forms, a factorized form as a function of a column vector that will be specified in the sequence and a linear form but in the context of our study, we consider only the factorized form.

**Factorized form of the propagation model *K* Factors**

The factorized form of the model *K* factors is written

$$L = [K_1 K_2 K_3 K_4 K_5 K_6] \times \begin{bmatrix} 1 \\ \log(d) \\ h_m \\ \log(h_m) \\ \log(h_b) \\ \log(h_b)\log(d) \end{bmatrix} \tag{4}$$

In the previous equation letting $K = [K_1 K_2 K_3 K_4 K_5 K_6]$ and

$$M = \begin{bmatrix} 1 \\ \log(d) \\ h_m \\ \log(h_m) \\ \log(h_b) \\ \log(h_b)\log(d) \end{bmatrix} \tag{5}$$

It follows that, the propagation model *K* factors can be written as

$$L = K \times M. \tag{6}$$

Table 4. *K* values of the *K* factors model.

| Parameter Name *K* | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | $K_{7\text{diffn}}$ | $K_{\text{clutter}}$ |
|---|---|---|---|---|---|---|---|---|
| **Parameter Value** | 149 | 44.9 | −2.49 | 0.00 | −13.82 | −6.55 | −0.8 | 0 |

This expression will be considered as the factorized form of the propagation model.

#### 3.1.2. The COST 231-Hata Model

The path loss is given by the following expression:

$$\begin{aligned} L_p &= 46.3 + 33.9\log(F) - 13.82\log(h_b) - a(h_m) \\ &+ (44.9 - 6.55\log(h_b))\log(d) + C_m \end{aligned} \tag{7}$$

Such as:

$$a(h_m) = (1.1\log(F) - 0.7) * h_m - (1.56\log(F) - 0.8) \tag{8}$$

With: Distance between mobile and base station (m); $F$: Transmission frequency (MHz); $h_b$: Height of base station (m); $h_m$: Height of mobile station (m); $a(h_m) = 0.001$ which is negligible. In the **following** $a(h_m)$ will therefore be assimilated to the value $a(h_m) = 0$. Table 5 gives the value of $C_m$ for different types of environment.

#### 3.1.3. The Free Space Model

As for the latter, it is expressed by the relationship:

$$L = 32.45 + 20\log(F) - 20\log(d) \tag{9}$$

#### 3.1.4. *K* Values for COST 231-Hata and Free Space

Table 6 present the free space model and Cost 231-Hata model in the form of $K$ factor vector.

### 3.2. Optimisation of the Propagation Model Using MOA

#### 3.2.1. Inspiration for the MOA Optimization Algorithm

The MOA optimization algorithm is based on the principles of magnetic field theory [4]. In MOA, the possible solutions are magnetic particles scattered in the search space with a long-range attractive force. In this respect, each magnetic particle has a measure of mass and magnetic field depending on its physical shape (its fitness), the fittest magnetic particles are more massive, with a stronger magnetic field. In terms of interaction, these particles are located in a structured population and apply a long-range attractive force to their neighbors. MOA simulates the electromagnetic forces between electromagnetic particles to move search agents through the search space. As the electromagnetic force is proportional to the fitness of the particles, search agents tend to be attracted to the fittest particles. Therefore, the search agents in this algorithm are improved by moving towards the best solutions.

Table 5. $C_m$ values in different areas.

| Zone | $C_m$ |
|---|---|
| **Urban Dense** | 3 |
| **Urban** | 0 |
| **Suburban** | −8 |
| **Rural** | −15 |

**Table 6.** Propagation models on the form of $K$ vector.

| Model | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ |
|---|---|---|---|---|---|---|
| COST 231-Hata | $46.3+33.9\log_{10}(F)$ | 44.9 | 0 | 0 | −13.82 | −6.55 |
| Free space | $32.45+20\log_{10}(F)$ | 20 | 0 | 0 | 0 | 0 |

### 3.2.2. MOA Procedure

The following procedure of MOA was presented by its conceptual authors in [4].

***Begin***

*t = 0*

*initialize $X^0$ with a lattice-like structure.*

***while not** termination condition **do***

***begin***

$t = t + 1$

*evaluate the individuals in $X^t$ and store their profits in magnetic field $B^t$*

*normalize $B^t$*

$$B_{ij} = \frac{B_{ij} - Min}{Max - Min}$$

*evaluate the mass $M^t$ for all particles* $M_{ij}^t = \rho \times B_{ij}^t + \alpha$

***for** all particles $x_{ij}^t$ in $X^t$ **do***

***begin***

*$F_{ij} = 0$*

*find $N_{ij}$*

***for** all $x_{uv}^t$ in $N_{ij}$ **do***

***begin***

$$F_{ij,k} = F_{ij,k} + \frac{\left(X_{uv,k}^t - X_{ij,k}^t\right) \times B_{uv}^t}{D\left(X_{ij,k}^t, X_{uv,k}^t\right)}$$

***end***

***end***

***for** all particles $x_{ij}^t$ in $X^t$ **do***

***begin***

$$V_{ij,k}^{t+1} = \frac{F_{ij,k}}{M_{ij,k}} \times R\left(l_k, u_k\right)$$

$$X_{ij,k}^{t+1} = X_{ij,k}^t + V_{ij,k}^{t+1}$$

***end***

***end***

***end***

The variables used in this algorithm are listed below:

$B_{ij}^t$ Magnetic field of particle $i$ at position $j$ at iteration $t$;

*Min*: Minimum value of the magnetic field;

*Max*: Maximum value of the magnetic field;

$M_{ij}^t$ The value of the mass of particle $i$ at position $j$ at iteration $t$;

$x_{ij}$ Particle $x$ of column $j$ and row $i$;

$N_{ij}$ Set of neighbouring particles of column $j$ and row $i$;

$D\left(X_{ij}^{t}, X_{uv}^{t}\right)$ Euclidean distance between the particles $X_{ij}^{t}$ et $X_{uv}^{t}$;

$V_{ij}^{t}$ The value of the velocity of particle *i* at position *j* at iteration *t*;

$F_{ij}^{t}$ The value of the force of particle *i* at position *j* at iteration *t*.

The vector *K* defined above will represent the magnetic particle in MOA formalism.

#### 3.2.3. Flowchart of the MOA Algorithm

As the different phases of the MOA algorithm have been clearly explained above, we present here the flowchart of the sequence of these different steps. We present here the flowchart of the sequence of these different steps in **Figure 4**.

#### 3.2.4. Determination Flowchart

**Figure 5** below shows the flowchart for determining the propagation model using the MOA algorithm.

In this flowchart, the data filtering was done according to the following criteria for distance and received signal strength; the thresholds are presented in **Table 7**.

Let $L_p = \{L_i\}_{i=1:N}$ be the set of loss values measured for *N* points at *N* given distances. Note further that the vector *M* depends on the distance *d*, for *d* variable $M = f(d)$. Thus, for *N* measurement points at different distances $d_i$, *M* will become a matrix of 6 rows and *N* columns.

The objective function will therefore be:

$$f = \min\left\{\frac{1}{N}\sum_{i=1}^{N}\left(L_p(i) - (K \times M_i)\right)^2\right\} \tag{10}$$

#### 3.2.5. Downlink Link Budget

However, it is important to remember that radio measurements provide three essential parameters at each measurement point: received power (in dBm); longitude and latitude (in degrees). Therefore, the value of the measured losses (Lp) is not explicitly obtained from the radio measurements. The link budget formula between a measurement point and the eNodeB provides the received power presented as follows:

$$\text{Prx} = \text{Ptx}(\text{sub carrier}) + \sum \text{gain} - \sum \text{Loss} - \sum \text{Marge} - \text{Lp} \tag{11}$$

Thus,

$$\text{Lp} = \text{Ptx}(\text{subcarrier}) + \sum \text{gain} - \sum \text{Loss} - \sum \text{Marge} - \text{Prx} \tag{12}$$

- **Prx** represents the power received at each measurement point;
- **Ptx** the transmit power of the **eNodeB**;
- The antenna **gain of the eNodeB**;
- The **gain of** the **mobile station**;
- Losses induced by cables and connectors and **Lp** the value of the measured losses.

**Ptx = 46 − 10log (Number of subcarriers)**

Furthermore, the values of the different distances are also implicit and are obtained from (the longitude and latitude of the eNodeB under consideration) and (the longitude and latitude of each measurement point). The vector *K* defined above will represent the magnetic particle in MOA formalism.

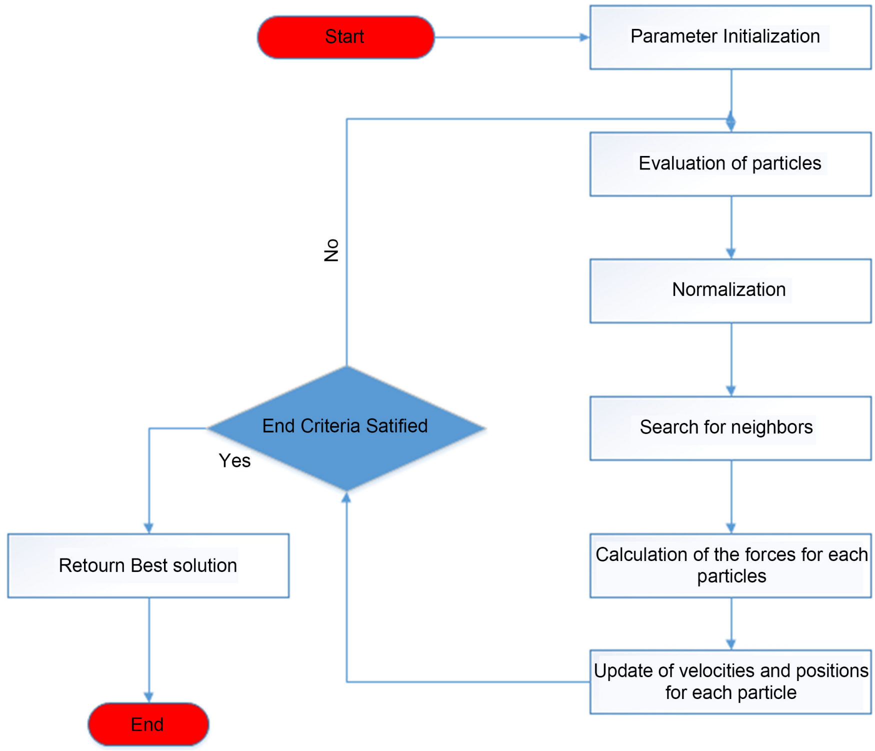


Figure 4. Flowchart of the MOA algorithm.

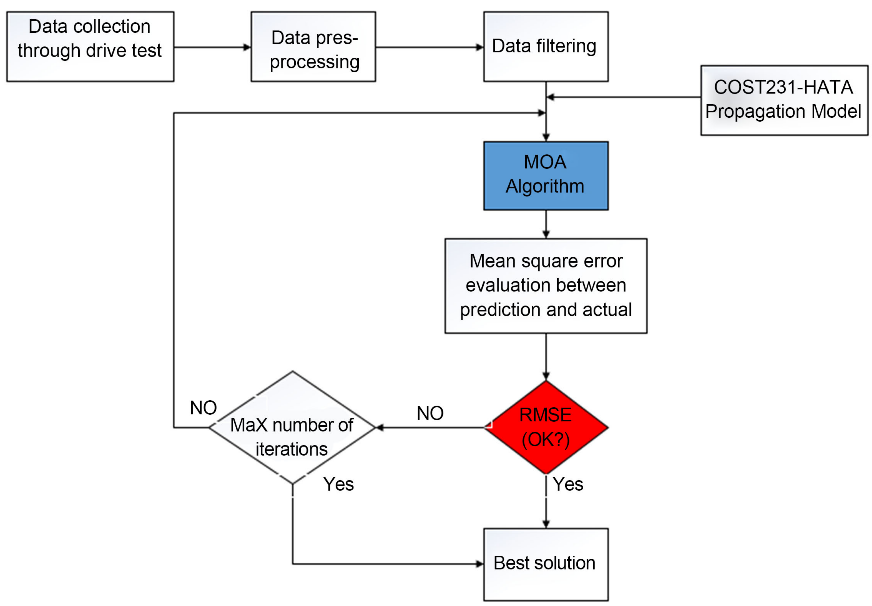


Figure 5. Flow chart of the implementation of the algorithm.

Table 7. Filtering criteria on distance and received power.

| Criterion | Distance (m) | Power (dBm) |
|---|---|---|
| Minimal | 100 | −125 |
| Maximum | 10 000 | −60 |

### 3.3. Generation of the Basic Family

The search space is between the standard COST231-Hata model and the free space propagation model which characterizes unobstructed propagation. The basic family will be generated according to the algorithm below:

**Algorithm**

***Start***

*K1el = 32.4 + 20 × log10(Fc)*;

*K1Cost = 46.3 + 33.9 × log10(Fc)*;

***For i = 1: PopulationSize***

*K1 = K1cost + (K1cost - K1el) × rand (1)*;

*K3 = −2.49 + 2.49 × rand (1)*;

*K4 = rand (1)*;

*K5 = −13.82 + 13.82 × rand (1)*;

*K6 = −6.55 × rand (1)*;

*K2 = 20 − (K6 × log10(Hb)) + ((36.8 − 20) × rand (1))*;

*P (i, :) = [K1 K2 K3 K4 K5 K6]*;

***End For***

***End***

This pseudo code is very important in that it defines integrity constraints for each of the parameters $K_1$, $K_2$, $K_3$, $K_4$, $K_5$ and $K_6$. Thus fixing the order of magnitude of their respective values. In this code, $K_{1cost}$ represents the parameter $K_1$ in the COST231-Hata model; $K_{1el}$ represents the parameter $K_1$ in the free space model. $P$ is the matrix representing the generated population and the population size corresponds to the number of measured distances.

### 3.4. Acceptance Criteria for an Optimized Propagation Model

An optimized propagation model is accurate if the square root of the mean square error between the actual and prediction measurements is less than 8 dB. Therefore, after obtaining the Best Solution from the execution of the MOA algorithm, we calculate the square root of the fitness function for the values of $K$ corresponding to this solution. The square root of the evaluation function is calculated as follows.

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(L_p\left(i\right)-\left(K\times M_i\right)\right)^2} \quad (14)$$

The solution is only saved if RMSE < 8 dB, which marks the end of the optimization process.

## 4. Results

After the implementation of MOA on drive tests data using Matlab as the programming tool, we obtained the curves below representing the real measurements in black, the COST231-Hata model in blue, the free space model in yellow, the model obtained by implementing the MOA algorithm in green. The model will be considered accurate if the RMSE between the predicted and measured values is less than 8 dB; (RMSE < 8 dB). Table 8 presents a summary of MOA parameters.

### 4.1. Zone A: Limbe_Central

From Figure 6, we can see that the prediction from MOA in green color fits well the cloud of points of field data with a RMSE of 2.4476 which is less than 8 dB. This means that this prediction is precise and accurate. In Figure 7, we can see that the fitness of MOA is converging after each iteration. From iteration 50, the fitness is not reducing and the value is constant. This is means that the best solution is reached and we can stop the calculations.

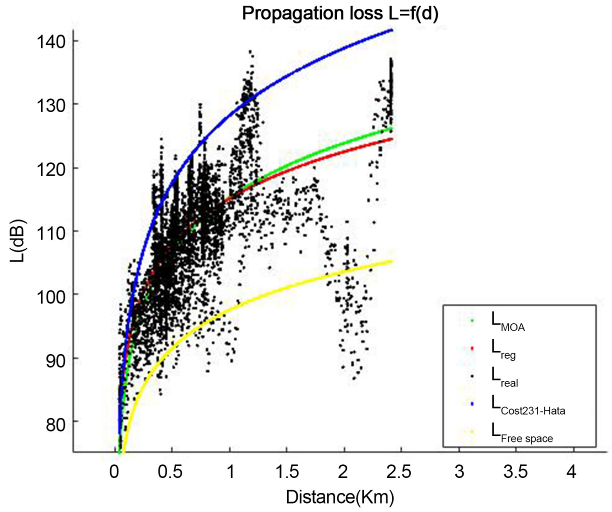


Figure 6. Actual Limbe_Central measurements VS predicted measurements.

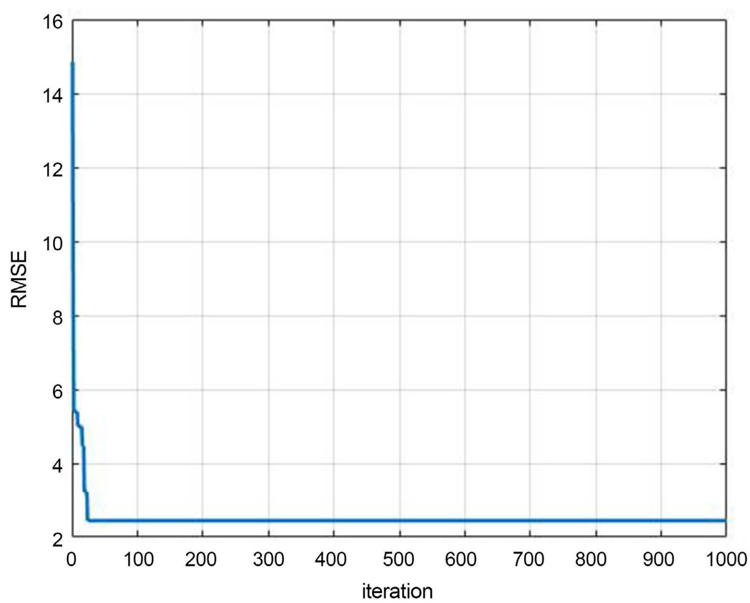


Figure 7. Convergence curve of the RMSE of the real measurements Limbe_Central.

Table 8. Definition of variable and MOA parameters.

| Method | MOA |
| --- | --- |
| Form of the problem variable | $K$ Vector, $(1 \times 6)$ matrix |
| Variable name | Particle |
| Set of variables | Magnet |
| Size of the set (Magnet) | Nc = 100 |
| Iterations number | Nit = 1000 |
| Fitness evaluation method | RMSE |
| Operations on variable | The force, velocity and position of particles |
| Evaluation and optimization method | Minimization of the RMSE |
| Stoping criteria | Based on the iterations numbers or on RMSE threshold |
| Number of parameters optimized | $2 \leq N \leq 6$ |

Table 9 below gives the results obtained by the MOA algorithm:

We notice that we have an RMSE < 8dB which confirms the reliability of the result.

## 4.2. Zone B: Limbe_Mile4

As for the case of Limbe_Central, we can see from Figure 8 that the prediction from MOA in green color fits well the cloud of points of field data with a RMSE of 2.3261 which is less than 8 dB. This means that this prediction is precise and accurate. In Figure 9, we can see that the fitness of MOA is converging after each iteration. After 650 iterations, the fitness is not reducing and the convergent is reached. This means that the best solution is reached and we can stop the calculations. For this area of the town, the convergence took more time than the one of Limbe_central (50 iterations).

Table 10 below gives the results obtained by the MOA algorithm in the area of Limbe Central:

We notice that we have an RMSE < 8dB which confirms the reliability of the result.

## 4.3. Zone B: Limbe_Kie_Village

As for the case of Limbe_Central, we can see from Figure 10 that the prediction from MOA in green color fits well the cloud of points of field data with a RMSE of 2.3725 which is less than 8 dB. This means that this prediction is precise and accurate. In Figure 11, we can see that the fitness of MOA is converging after each iteration. After 710 iterations, the fitness is not reducing and the convergent is reached. This means that the best solution is reached and we can stop the calculations. For this area of the town, the convergence took more time than the one of Limbe_central (50 iterations).

Table 11 below gives the results obtained by the MOA algorithm in Kie village area.

We notice that we have an RMSE < 8dB which confirms the reliability of the result.

Table 9. Results obtained in Limbe_Central.

| Zone | Results | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | RMSE |
|---|---|---|---|---|---|---|---|---|
| A | MOA | 126.6158 | 37.9067 | −1.3237 | 0.9004 | −6.4497 | −6.3879 | **2.4476** |
| | Linear regression | 139.2444 | 34.2231 | −2.4900 | 0 | −13.820 | −6.55 | **7.0993** |
| | COST231-Hata | 156.65 | 44.9 | 0 | 0 | −13.82 | −6.55 | **13.3621** |
| | Free space | 97.55 | 20 | 0 | 0 | 0 | 0 | **18.0964** |

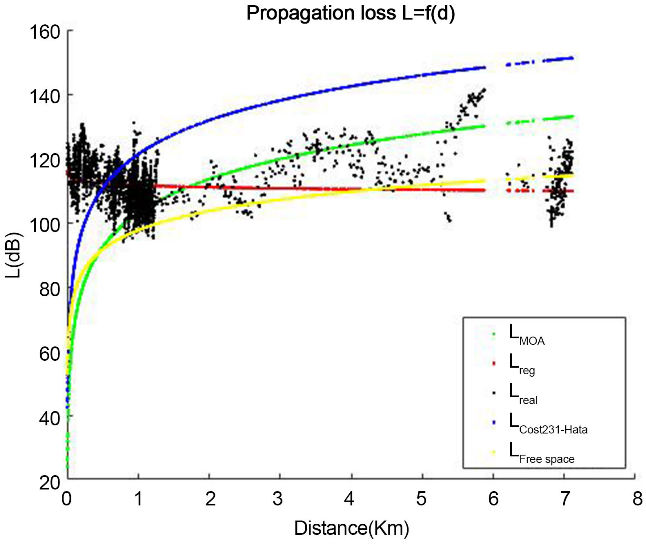


Figure 8. Actual measurements Limbe_Mile4 VS predicted measurements.

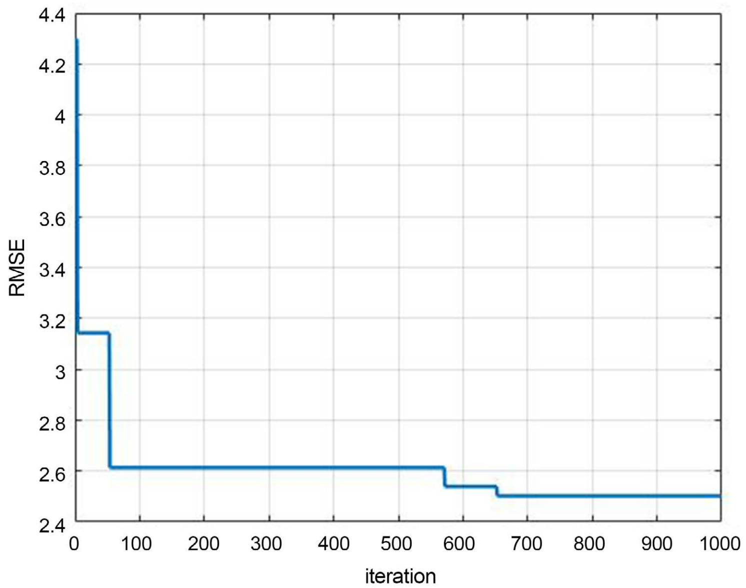


Figure 9. Convergence curve of the RMSE of the real measurements Limbe_Mile4.

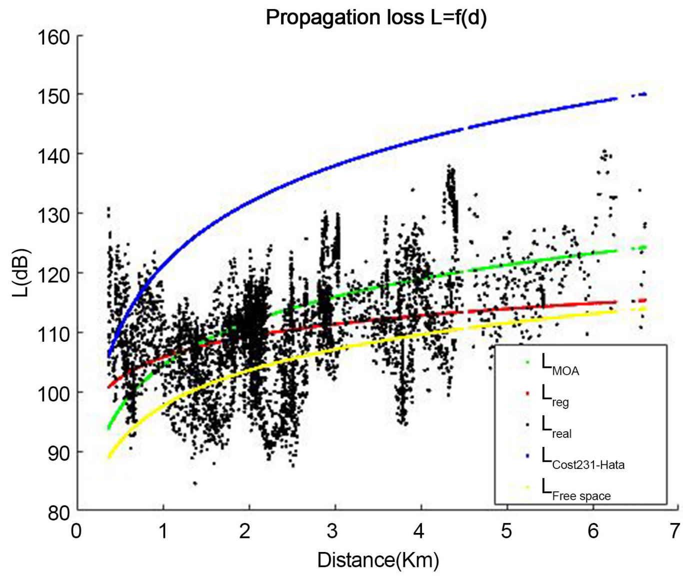


**Figure 10.** Actual measurements Limbe_Kie_village VS predicted measurements.

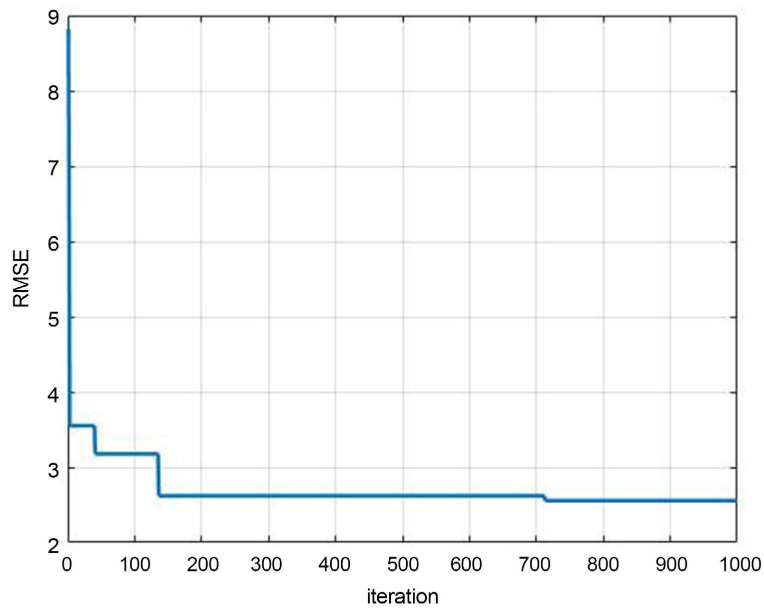


**Figure 11.** Convergence curve of the RMSE of the real measurements Limbe_Kie_village.

**Table 10.** Results obtained in Limbe_Mile4.

| Zone | Results | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | RMSE |
|---|---|---|---|---|---|---|---|---|
| B | **MOA** | 121.4517 | 40.2682 | −2.1490 | 0.6924 | −10.1144 | −5.8210 | **2.3261** |
| | **Linear regression** | 135.6946 | 7.6834 | −2.4900 | 0 | −13.82 | −6.55 | **6.9306** |
| | **COST231-Hata** | 156.65 | 44.9 | 0 | 0 | −13.82 | −6.55 | **19.0282** |
| | **Free space** | 97.55 | 20 | 0 | 0 | 0 | 0 | **19.8259** |

Table 11. Results obtained in Limbe_Kie_village.

| Zone | Results | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | RMSE |
|---|---|---|---|---|---|---|---|---|
| C | **MOA** | 123.0203 | 24.0548 | −1.0419 | 0.7205 | −10.1309 | −1.1428 | **2.3725** |
| | **Linear regression** | 129.9353 | 21.3255 | −2.490 | 0 | −13.82 | −6.55 | **8.4882** |
| | **COST231-Hata** | 156.65 | 44.9 | 0 | 0 | −13.82 | −6.55 | **25.3054** |
| | **Free space** | 97.55 | 20 | 0 | 0 | 0 | 0 | **10.3142** |

Table 12. Results summary.

| $K$ | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ | RMSE |
|---|---|---|---|---|---|---|---|
| **Limbe_Central** | 126.6158 | 37.9067 | −1.3237 | 0.9004 | −6.4497 | −6.3879 | **2.4476** |
| **Limbe_Mile4** | 121.4517 | 40.2682 | −2.1490 | 0.6924 | −10.1144 | −5.8210 | **2.3261** |
| **Limbe_Kie_village** | 123.0203 | 24.0548 | −1.0419 | 0.7205 | −10.1309 | −1.1428 | **2.3725** |

Table 13. Evaluation of the average propagation model.

| Final solution | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ | $K_6$ |
|---|---|---|---|---|---|---|
| City of Limbé | 123.6959 | 34.0765 | −1.5048 | 0.7711 | −8.8983 | −4.4505 |

## 4.4. Summary of Results

The previous results prove that MOA can optimize propagation model with a very good precision. By retaining only the solutions that gave an RMSE < 8 dB, *i.e.* those in zones A, B and C we have the mean vector recorded in Table 12.

The optimization is globally good in each of the zones considered. The value of RMSE < 8 dB in each of them proves the reliability of the result. Thus, all three zones are taken into account in the final propagation model. An average solution (average value of the best solution retained per zone) can be deduced, which will represent the optimized propagation model for the city of Limbé. The final result and the corresponding formula are given below and it is presented in Table 13.

$$K_{\text{Limbe}} = \left[K_{1\text{Average}}\ K_{2\text{Average}}\ K_{3\text{Average}}\ K_{4\text{Average}}\ K_{5\text{Average}}\ K_{6\text{Average}}\right] \tag{15}$$

The final expression of our propagation model will therefore be:

$$\begin{aligned} L_p = {} & 123.6959 + 34.0765 \times \log \times (d) - 1.5048 \times H_m + 0.7711 \times \log(H_m) \\ & - 8.8983 \times \log(H_b) - 4.4505 \times \log(H_b) \times \log(d) \end{aligned} \tag{16}$$

We can see from these results that MOA is efficient to optimize radio propagation model such that the new obtained model fit well the radio environment. The new model can be used for an optimal radio network planning for new network deployment or network expansion.

## 5. Conclusion

This paper presents the results obtained by implementing the MOA optimization algorithm in order to set up a propagation model adapted to the physical environment of the city of Limbe. It was found that standard propagation models such as Cost231-Hata and the free space model are not suitable, so it is important to optimize the said models to obtain similar models but represent the considered propagation environment. The MOA optimization algorithm used allowed us to obtain a propagation model of the city of Limbe with a RMSE value between 2.3261 dB and 2.4476 dB while that of the Cost231-Hata model varies from 13.3621 dB to 25.3054 dB, the one free space model from 10.3142 dB to 19.8259 dB, and the optimization by linear regression varies from 6.9306 dB to 8.4882 dB. We conclude that the new model is more accurate and better represents the propagation in the city of Limbe than the standard COST231-Hata models and the linear regression method. This approach could be applied to the determination of propagation models for any town and for the deployment of enterprise LTE solution developed for smart cities initiative where the LTE network is used not only for traditional service like voice and data, but also for trunking solution including voice, image and video dispatching, this LTE solution can also carry urban video surveillance, police and security internal communications and other possibilities.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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