Planning and Optimization Approach using Genetic Algorithms of a New Generation Cellular Network Capitalizing on the Existing Sites

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Abstract: ***In this paper we model the problem of base station migration as a question of optimization by genetic algorithms in order to minimize a target goal which is a weighted function of network coverage, traffic, energy consumption and the cost of the infrastructure. The model takes as input an area of interest, a set of existing sites, a maximum number of sites, and outputs the optimal number and locations required for sites, including existing sites and new sites. The goal here is to minimize the cost of deploying the new network by reusing existing network sites as much as possible while ensuring that traffic coverage is good and energy consumption is reduced. We proposed and implemented an algorithm to solve the optimization problem formulated based on a model of distribution of mobile stations and the locations of existing sites as well as new sites.***

Keywords: Cellular network, Genetic Algorithm, Optimization, Planning.

1. Introduction

Wireless communication networks are developing and implementing themselves at a vertiginous speed translated by the emergence of new generations which are driven by the growth in the demand for the traffic capacity of users who require an ever greater throughput. To meet the users demand and have a competitive edge of the market, telecom operators continually update their networks while ensuring control over costs and the quality of service provided. To meet this requirement, the reuse of existing sites is often employed to deploy new networks. This is because, the co-location of new network (4G/5G) sites on existing network (2G/3G) sites is likely to generate savings for the operator in terms of site acquisition, site rental, deployment and maintenance of the network. However, the reuse of the technical sites of a previous generation networks (2G/3G) for the deployment of a new generation network (4G or 5G), out of an adequate approach, is not able to ensure the desired coverage and quality of service in the area of interest. In the sense that, the coverage radii of new generation network (4G/5G) shrink due to their ability to support higher data rates and thus giving rise to a smaller traffic coverage than previous generation network (2G/3G). Reusing the resources of an existing network coupled with a reduction in the number of new sites to be deployed as part of the migration process to a new network can affect its performance thus creating fewer opportunities for lower costs. By intelligently choosing the cells to be completed, an operator can reduce the number of cells to be deployed in a network with a minor impact on traffic coverage. To cope with these constraints of quality of service and economy, an appropriate approach to optimize the planning of the cellular network is therefore necessary. This approach of optimal deployment of the network involves the solving of an optimization problem that is highly combinatorial and of a great complexity for which the exhaustive search of all the candidate solutions would be impossible [10]. Methods are therefore used, that make it possible to search, in a reasonable time, for approximate optimal solutions. Therefore, this study contributes to solving the problem of optimal deployment of a new network by considering the existing infrastructures. This contribution is reflected in the development of a simple and innovative genetic algorithm to achieve the targeted objectives. The criteria to be satisfied are the reduction of network blackout areas, new sites to be deployed, energy consumed and uncovered traffic. The rest of the article is structured as follows: section 2 presents the literature review, sections 3 and 4 formulate the problem and present its complexity, section 5 presents the methodology used and section 6, 7 and 8 present the area of interest, the pseudo code, the results and comments.

2. Literature Review

Certain research works have focused on 4G network planning based on coverage, capacity, transmission efficiency and energy consumption. An optimization scheme for location planning based on coverage, capacity and cost criteria is developed in [2] for the LTE network. A hierarchical planning approach to reduce total energy consumption for both users and cells is proposed in [3]. A new mathematical model for 4G base station planning is proposed in [4] with minimum cost, coverage and maximum capacity objectives at the same time. However, the above work focuses primarily on how to plan a network based on theoretical methods far from the practical needs of operators. Other works have focused on the planning of cellular networks such as [1] where the 4G LTE network is designed in the 1800 Mhz frequency band and the calculation model focused on the path loss. A method of optimization by mimetic algorithm (genetic algorithm + local search) of the placement of sites in a WCDMA network taking into account the cost of the site and the power of a test point assigned to a given site is formulated in [6]. A Genetic Algorithm optimization approach to eNodeB locations that minimizes the energy consumption of the LTE radio subsystem is developed in [7]. A Genetic Algorithm-based method that optimizes base station locations by minimizing investment costs while meeting coverage and capacity requirements in a context of network heterogeneity (Macro BS, Micro BS, Relay Node) and inhomogeneity of traffic (users average throughput (CN) and broadband (HS)) is proposed in [10]. The authors of [8] propose an abstract mathematical model associated with genetic algorithms to solve the global planning problem of a 4G/LTE cellular network by aiming at minimizing the costs of links and intercellular transfers. In paper [9], the authors use several heuristic approaches such as the differential evolution algorithm (DE) and the real genetic algorithm (RGA) to optimize the planning of 5G networks with decision variables such as transmission power and the location of the transmitter (eNodeB). These studies consider areas of interest devoid of any infrastructure and assume that the operator would have unlimited financial resources. In fact the process of technological upgrading is strongly influenced by available resources, equipment and support infrastructures. Therefore, reuse of existing infrastructures for the deployment of a new network is a highly desired option.

3. Problem formulation

In this model, we address the problem of optimally placing new sites combined with existing sites within the framework of migrating from a current network to a new cellular network. This placement must ensure the coverage of the area of interest, the satisfaction of the demand for user's traffic while reducing the number of sites and the amount of energy used.

For this to be done, we consider an area of interest $V = \{1, \ldots, n\}$ a set of $I = \{1, \ldots, N_b\}$ of a given configuration of base stations and a set of client location $J = \{1, \ldots, l\}$. The set I contains a number n_{fixe} of existing sites with locations known and n_{new} new sites arbitrarily placed so that $N_b = n_{fixe} + n_{new}$.

The configuration of the base station contains the geographic location, antenna height, transmitter power, tilt, azimuth, cost, and capacity. It also contains the adequate propagation model, the method of calculating the cell radius and the interference. Each customer located in the area of interest is characterized by its geographical position and its traffic demand.
The coordinates of a fixed site are given by $z_{j,fixe} = (x_{j,fixe}, y_{j,fixe})$ and those of a new site are given by $z_{j,new} = (x_{j,new}, y_{j,new})$. While the parameters of a fixed site are given by $s_{j,fixe} = (z_{j,fixe}, p_{j,fixe}, r_{j,fixe}, e_{j,fixe})$ and those of a new site are given by $s_{j,new} = (z_{j,new}, p_{j,new}, r_{j,new}, e_{j,new})$. The result is a set of sites $G = (z_i, p_i, r_i, e_i \ldots\ldots)$ $i = 1, \ldots\ldots, N_0$ that satisfy the planning objectives. The resultant number N_0 is less than N_b and contains n_1 sites from the n_{fixe} fixed sites and n_2 sites from the n_{new} new sites. In our approach we are going to limit the parameters of $s_{j,fixe} = (z_{j,fixe}, p_{j,fixe}, r_{j,fixe}, e_{j,fixe})$ and $s_{j,new} = (z_{j,new}, p_{j,new}, r_{j,new}, e_{j,new})$ and $G = (z_i, p_i, r_i, e_i)$ $i = 1, \ldots\ldots, N_0$. To complete this formulation, we consider the following notations:

Table 1: Description of the other symbols

Symbol	*Description*
A_T	Total area of the zone of interest
A_s	Area covered by a site s
e_s	State of a site s (0 for an inactive site and 1 for an active site)
r_s	Radius of site s
PL	Path loss between a site and a given point
f	Operating frequency
h_b	Height of the Base Station
h_m	Height of the Mobile Station
U_T	Total number of users in the zone of interest
U_S	Total number of users satisfied
L_{ij}	Overlap area between site i and site j

3.1 Objective

Several factors must be considered when planning a wireless network. One of these factors is expenses incurred by the wireless network operator. Therefore the main purpose of this article is to deploy an appropriate number of sites while reducing the operator's capital and operating expenses and, by maximizing traffic demand coverage.

3.1.1 Minimization of network blackout areas
The first objective is the minimization of the blackout zone that is to say, the minimization of parts of the area of interest where the service is not available. In other words, it is a question of maximizing the area in which the service is available, that is the coverage area. This objective can be formally evaluated by the following formula:

$$f_c(G) = Min \frac{A_T - \sum_{s=1}^{N_b} A_S * e_s}{A_T} \quad (1)$$

3.1.2 Minimization of uncovered traffic
The second objective is the minimization of uncovered users. This objective aims at maximizing the satisfaction of the

users in the area of interest. This objective can be formally evaluated by the following formula:

$$f_t(G) = Min \frac{U_T - \sum_{s=1}^{N_b} U_S * e_s}{U_T} \quad (2)$$

$$a\ user\ u_j \in U_S \Rightarrow d(u_j, s) \le r_s \quad (3)$$

$$d(u_j, s) = \sqrt{(x_s - x_{u_j})^2 + (y_s - y_{u_j})^2} \quad (4)$$

3.1.3 Minimization of the number of sites used

The third objective of achieving deployment savings by reducing the maximum number of sites considered is to minimize the number of sites resulting from the configuration of existing sites and new sites to be deployed in the area under study to ensure the two previous criteria. This objective can be formally evaluated by the following formula:

$$f_e(G) = Min \frac{\sum_{s=1}^{N_b} e_s}{N_b} \quad (5)$$

$$e_s = \begin{cases} 1 & if\ the\ site\ is\ active \\ 0 & if\ the\ site\ is\ inactive \end{cases} \quad (6)$$

3.1.4 Minimization of energy consumption

The fourth objective aims not only to enable the operator to save operating costs by reducing the energy consumption generated by radio equipments, but also to reduce the exposure of users to electromagnetic radiation. This objective can be formulated as follows:

$$f_p(G) = Min \frac{\sum_{s=1}^{N_b} p_s * e_s}{N_0 * p_{\max}} \quad (7)$$

3.2 Constraints

The constraints that must be met in any feasible solution can be formulated as follows:

1) *For every site* $s_i = (z_i, p_i, r_i, e_i)$

$$x_{\min} \le x_{z_i} \le x_{\max} \quad (8)$$

$$y_{\min} \le y_{z_i} \le y_{\max} \quad (9)$$

$$p_{\min} \le p_i \le p_{\max} \quad (10)$$

$$e_{\min} \le e_i \le e_{\max} \quad (11)$$

his constraint restricts site settings within the range provided for this purpose.

2) Constraint of eliminating the superposition of sites

$$e_{s_i} = 0\ \ if\ z_i = z_j\ and\ r_i < r_j \quad (12)$$

$$e_{s_j} = 0\ \ if\ z_i = z_j\ and\ r_i \ge r_j \quad (13)$$

$$L_{ij} = \begin{cases} 0\ \ if\ \ z_i = z_j\ and\ r_i < r_j \\ 0\ \ if\ \ z_i = z_j\ and\ r_i \ge r_j \\ 0\ \ if\ \ r_i + r_j \le d_{ij} \\ r_i^2 \cos^{-1}\left(\frac{d_{ij}^2 + r_i^2 - r_j^2}{2d_{ij}r_i}\right) + r_j^2 \cos^{-1}\left(\frac{d_{ij}^2 + r_j^2 - r_i^2}{2d_{ij}r_j}\right) - \\ \frac{1}{2}\sqrt{(-d_{ij}+r_i+r_j)(d_{ij}+r_i-r_j)(d_{ij}-r_i+r_j)(d_{ij}+r_i+r_j)} \\ if\ \ r_i + r_j > d_{ij} \quad [22] \end{cases} \quad (14)$$

3) The constraint of eliminating excessive overlap.

This constraint makes it possible to limit the overlapping area between two (02) cells to at most α (0≤α≤1) of the surface of the smallest cell. This constraint should equally make it possible to limit inter-cell interference, to increase the area covered and to reduce in another way the exposure of the user to electromagnetic radiation. In our case α = 0.2, that is to say, we allow only an overlap between two neighboring cells of at most 20% of the area of the smallest cell.

4. Complexity

Considering the assumptions made in Section 3, the size of the solution space is [18]:

$$E = C_{n_{fixe}}^{n_1} x C_{n_{new}}^{n_2} x (P_{\max} - P_{\min} + 1)^{N_b} x (e_{\max} - e_{\min} + 1)^{N_b} \quad (16)$$

$$E = \frac{n_{fixe}!}{n_1!(n_{fixe} - n_1)!} x \frac{n_{new}!}{n_2!(n_{new} - n_2)!} x (P_{\max} - P_{\min} + 1)^{N_b} x (e_{\max} - e_{\min} + 1)^{N_b}$$

Suppose that:

$N_b = 244[13], n_{fixe} = 100, n_{new} = 144$

$N_0 = 220, n_1 = 100, n_2 = 120$

$P_{\max} = 46dB, P_{\min} = 43dB, e_{\max} = 1, e_{\min} = 0$

$$E = \frac{100!}{100!0!} x \frac{144!}{120!24!} x 4^{244} x 2^{244} = 3.02x10^{247}$$

With a state of art computer with a processing capacity of 1 terabit /s, the search for an optimal solution will need a time of: $T = \frac{3.02x10^{247}}{10^{12} x3600x24x365} = 9.5x10^{247}\ years$

This is clearly unrealistic and unachievable in a reasonable time. A heuristic or meta-heuristic approach is therefore recommended. Existing metaheuristic methods, like genetic algorithms have shown more efficiency in the search for the global optimum than simulated annealing or taboo research [19]. So we choose the meta-heuristic "genetic algorithm" for solving our problem.

5. Resolution approach by Genetic algorithm

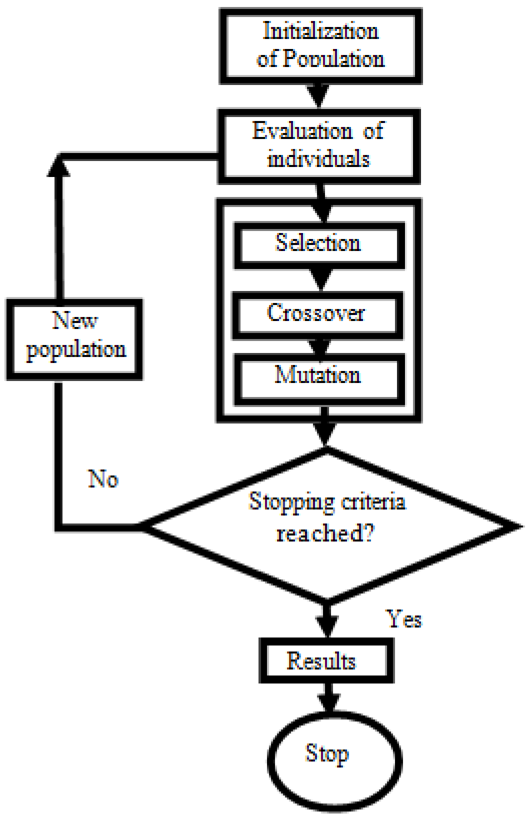

Figure 1: Flowchart of the genetic algorithm [16]

Genetic algorithm as developed by John Holland and his collaborators in 1960 and 1970 is a model, which is an abstraction of biological evolution based on Charles Darwin's theory of natural selection [14]. Genetic algorithm approaches are the most widely known current type of metaheuristic calculation method. They are used in many research works in all scientific fields, because they have many advantages in optimization [15]:

- The ability to deal with complex problems;
- The possibility of treating different types of optimization according to their objective functions (linear or non-linear).

The genetic algorithm includes in the optimization study, the genetic operators that are selection, crossover and mutation which occupy a large part of the resolution of the problem. The following lines explain the representation and the genetic operators used.

5.1 Representation of the population

$$B=\{(x_1,y_1,p_1,r_1,e_1),.....,(x_{n_{fixe}},y_{n_{fixe}},p_{n_{fixe}},r_{n_{fixe}},e_{n_{fixe}}),$$
$$(x_{n_{fixe}+1},y_{n_{fixe}+1},p_{n_{fixe}+1},r_{n_{fixe}+1},e_{n_{fixe}+1}),....,(x_{N_b},y_{N_b},p_{N_b},r_{N_b},e_{N_b})\}$$

A configuration of users is given by:

$$U=\{(X_1,Y_1,d_1),.......,(X_u,Y_u,d_u),.......,(X_l,Y_l,d_l)\}$$

X_i : abscissa of user i

Y_i : ordinate of user i

d_i : traffic demand of user i

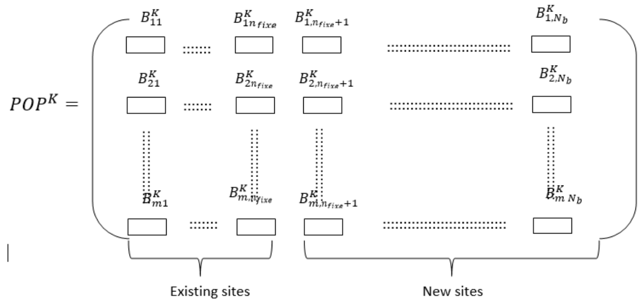

Figure 2: Representation of the population of the K[th] generation

It is worth noting that for each column $j\left(1\le j\le n_{fixe}\right)$ $\left(B_{ij}^{k}\right)$ has the same values for $\left(1\le i\le m\right)$.

5.2 Objective function [20] [21]

$$f(G)=Min\left[w_c f_c(G)+w_t f_t(G)+w_e f_e(G)+w_p f_p(G)\right] \qquad (17)$$

$$f(G)=Min\left[\begin{array}{l} w_c*\dfrac{A_T-\sum_{s=1}^{N_b}A_s*e_s}{A_T}+w_t*\dfrac{U_T-\sum_{s=1}^{N_b}U_s*e_s}{U_T}\\ +w_e*\dfrac{\sum_{s=1}^{N_b}e_s}{N_b}+w_p*\dfrac{\sum_{s=1}^{N_b}p_s*e_s}{N_0*p_{max}}\end{array}\right]$$

$$w_c+w_t+w_e+w_p=1 \qquad (18)$$

5.3 Genetic Operators

Crossover:

The crossover process is an approach to exploit the best features of the present chromosomes by combining them to improve their adaptability. This operator randomly chooses a locus and exchanges the sub-sequences before and after this locus between two parent chromosomes to create a child chromosome pair. One or more random crossover points may be chosen to further assist the operation. Other types of crossover exist as the uniform crossover [17]. We use in this study, the crossover in one point and two points.

Mutation:

It is a genetic operation that is used for exploration by randomly altering the genes of a chromosome in order to discover new horizons and to reveal new traits corresponding to the exploitation of new zones in the search space. The mutation helps to diversify the population thus allowing the genetic algorithm to avoid local optima while opening the way towards the global optimum [17]. Among the existing mutation approaches, we will use in this exercise the mutation in one point where the genes at a random position of a given chromosome are changed randomly.

Selection:
This process allows an individual from a given population to be selected for subsequent recombination or crossover operation. The more suitable the individual is, the more likely it can be selected for the next step [17]. We will use in this work the selections by roulette, tournament and random.

5.4 Stopping criteria

The algorithm ends when the number of iterations have been attained or when the Objective function converges.

6. Area of interest

The area of interest used in our study is a simulation of the mapping of the city of Yaoundé with an area of 183 km^2 or 13.53 km x 13.53 km. This space is represented in Cartesian coordinates by abscissas varying in the range [1 to 14.53] and the ordinates varying in the range [2 to 15.53]. The sizing done in [13] shows that 244 sites are needed in the area. To take into account the recovery of the cells by 20%, we will multiply the previous number of sites by 1.20 to obtain 293 sites. We assume that our area has 100 existing sites and n_{new} sites to complete among the 193 random sites.

7. Pseudo Code

Initialize the vector of n_{fixe} existing sites, v_{fixe} Initialize the population of n_{new} random sites, POP_{new} making sure that the generated sites do not coincide with existing ones
Evaluate each chromosome of (POP_{new}) merge with v_{fixe}

While the stopping condition is not reached

Select POP'_{new} by roulette or Tournament or random

Crossover POP'_{new} chromosomes according to crossing probability to obtain POP''_{new}

Re-evaluate each chromosome of POP''_{new} merge with v_{fixe}

Mutate POP''_{new} according to mutation probability to obtain POP'''_{new}

Re-evaluate each chromosome of (POP'''_{new}) merge with v_{fixe}

Build a new population by merging POP_{new} , POP''_{new} and POP'''_{new} , sort it and extract the optimum of this generation which is $POP_{new}(1)$ merge with v_{fixe}

Extract the n_{new} first elements of the merged population POP_{new} , POP''_{new} and POP'''_{new} in order to constitute the population of random sites of the next generation

End While
End.

8. Results and Comments

The simulation results have been obtained by using MATLAB version R2018a

8.1 Simulation parameters

8.1.1 System parameters
The system parameters are defined as in [13].

8.1.2 Parameters of Genetic Algorithm

Table 2: Parameters of the genetic algorithm

Parameter	Value
A_T (km^2)	180 (13.41x13.41)
U_T	1000
n_{fixe}	100
n_{new}	193
x_{min}	1
x_{max}	14.53
y_{max}	15.53
p_{min} (dB)	43
p_{max} (dB)	46
e_{min}	0
e_{max}	1
$Pcross$ (crossover probability)	0.7
P_{mut} (mutation probability)	0.08
m (population size)	100
beta (selection pressure for roulette)	8
Tournament size – selection by tournament	3

8.2 Results by selection and crossover type

Considering:
The coverage rate:

$$f'_c(G)=1-f_c(G) \qquad (19)$$

The reduction of energy consumption rate:

$$f'_p(G)=1-f_p(G) \qquad (20)$$

The rate of reduction of site number:

$$f'_e(G)=1-f_e(G) \qquad (21)$$

For case (a): $w_c = 0.4; w_t = 0.3; w_p = 0.2; w_e = 0.1;$
number of individuals: 100
Number of iterations: 20000; *mutation: one point* :

Table 3: Results for case (a)

Selection Type	Cross-over Type	$f'_c(G)$ (in %)	$f'_p(G)$ (in %)	$f'_e(G)$ (in %)	$f_t(G)$ (in %)	$f(G)$
Roulette	One point	79.21	2.80	42.32	99.9	0.33
	Two points	80.84	2.42	41.29	99.9	0.33
Tournament	One point	79.69	2.66	42.32	99.9	0.33
	Two points	79.45	2.76	41.63	99.9	0.33
Random	One point	82.04	2.51	40.61	100	0.32
	Two points	81.51	2.55	40.61	99.8	0.32

For case $(b): w_c = 0.3; w_t = 0.2; w_e = 0.2; w_p = 0.3;$ *number of individuals*:100
Number of iterations:20000; *mutation*:*one point* :

Table 4: Results for case (b)

Selection Type	*Cross-over Type*	$f_c'(G)$ (*in %*)	$f_p'(G)$ (*in %*)	$f_e'(G)$ (*in %*)	$f_t(G)$ (*in %*)	$f(G)$
Roulette	One point	80.36	2.55	41.97	99.8	0.46
	Two points	80.47	2.60	41.63	99.7	0.46
Tournament	One point	78.85	2.82	42.66	99.8	0.47
	Two points	80.80	2.51	41.63	100	0.46
Random	One point	76.76	2.55	46.07	100	0.46
	Two points	79.14	2.56	43.34	99.7	0.46

8.3 Results with roulette selection, two point crossover case (a)

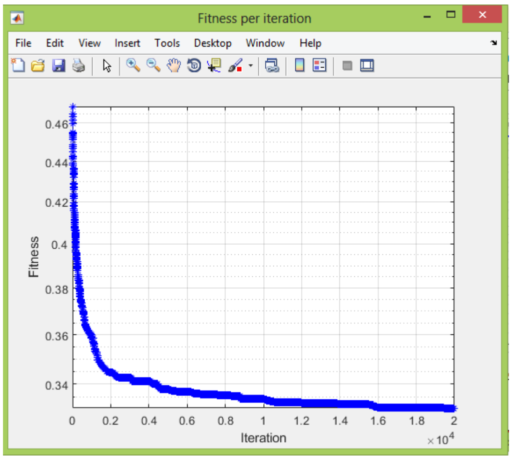

Figure 3: Evolution of the fitness according to the number of iterations

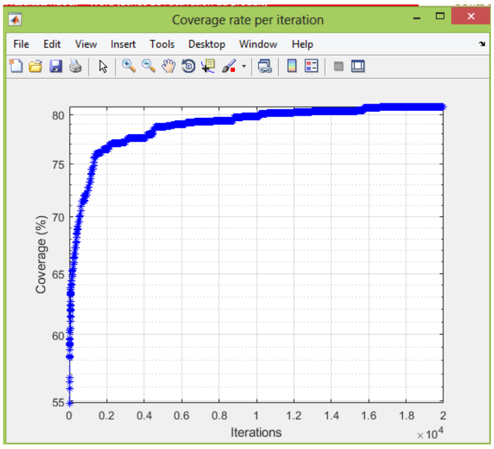

Figure 4: Evolution of the coverage rate according to the number of iterations

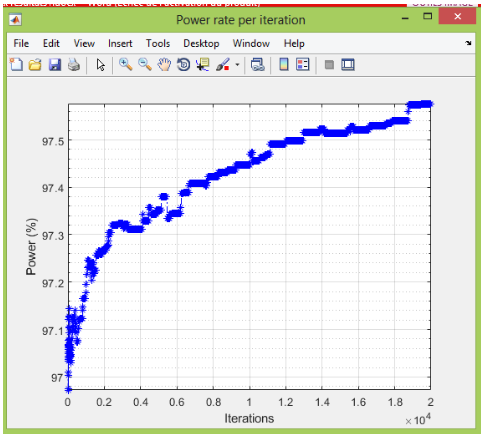

Figure 5: Evolution of the power used rate according to the number of iterations

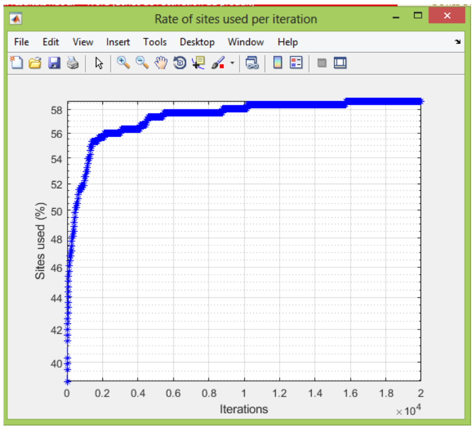

Figure 6: Evolution of the rate of sites used according to the number of iterations

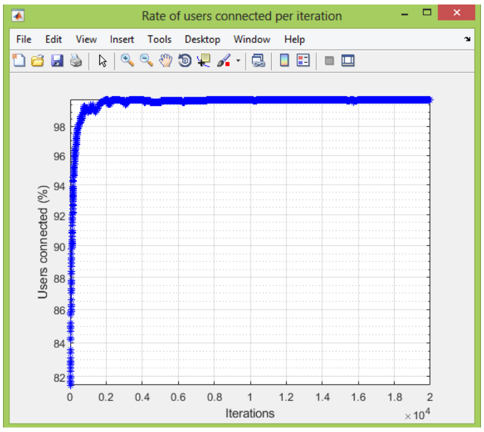

Figure 7: Evolution of the rate of users connected according to the number of iterations

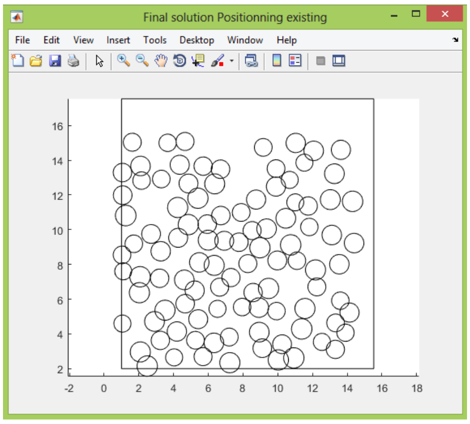

Figure 8: positioning of fixed sites on the area of interest

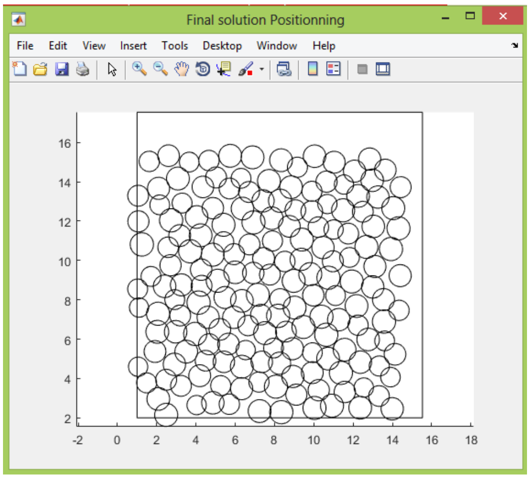

Figure 9: Final positioning of sites (fixed and added) on the area of interest

8.3 Results with Tournament Selection, One Point Crossover case b

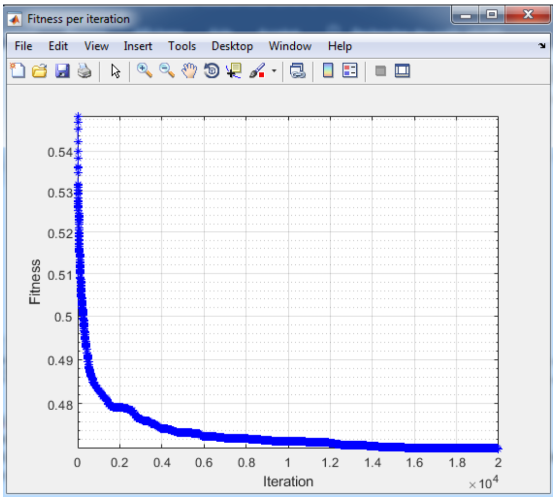

Figure 10: Evolution of the fitness according to the number of iterations

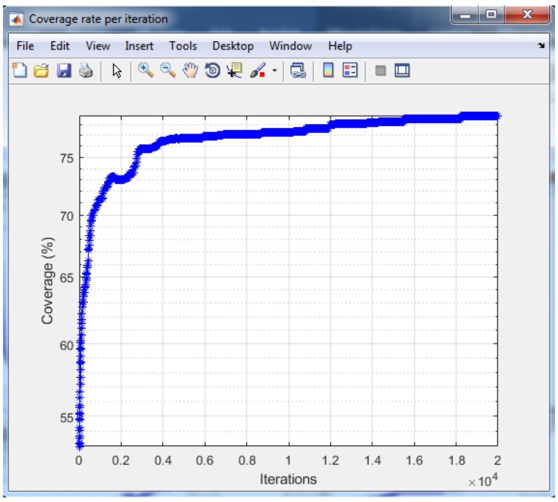

Figure 11: Evolution of the coverage rate according to the number of iterations

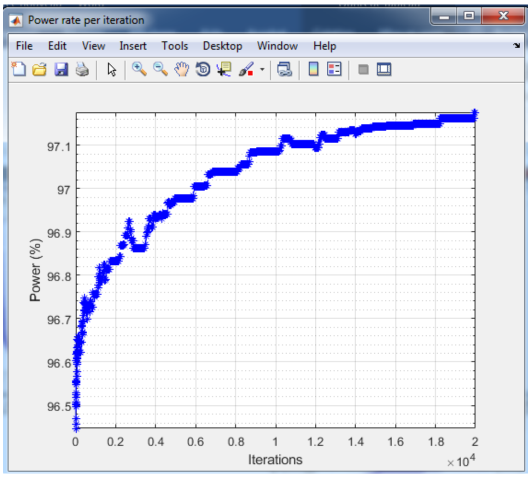

Figure 12: Evolution of the power used rate according to the number of iterations

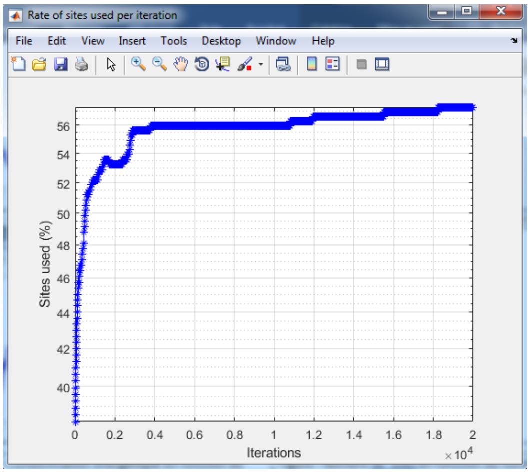

Figure 13: Evolution of the rate of sites used according to the number of iterations

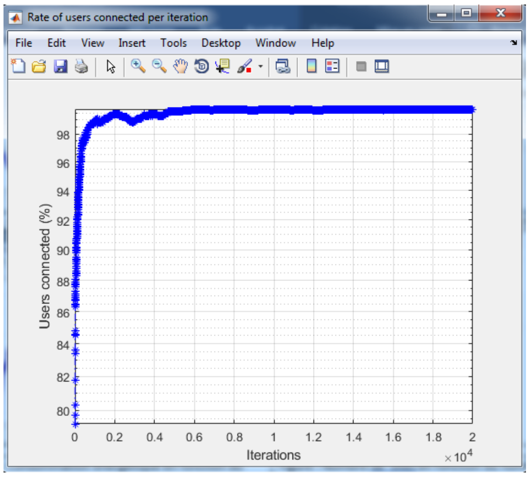

Figure 14: Evolution of the rate of users connected according to the number of iterations

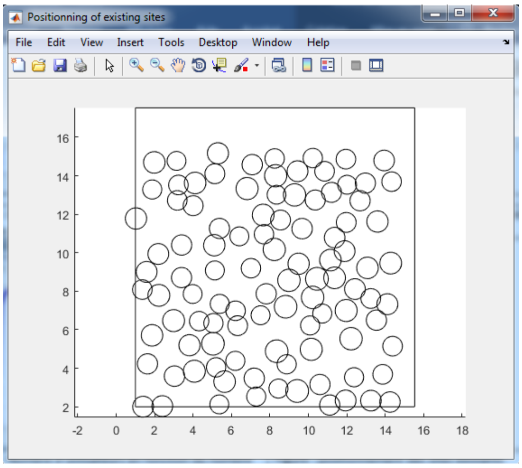

Figure 15: Positioning of fixed sites on the area of interest

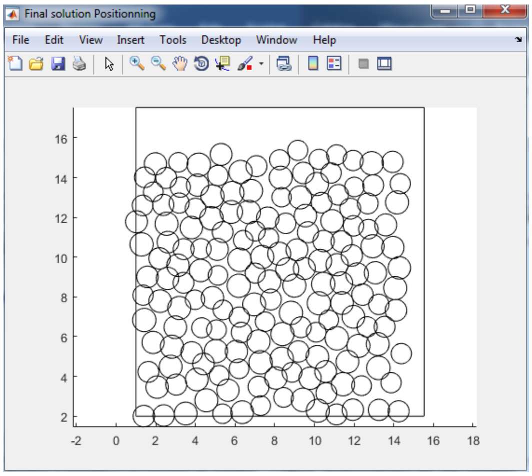

Figure 16: Final positioning of sites (fixed and added) on the area of interest

8.4 Comments

The results above show the evolution of the planning objectives that we initially set ourselves that are, the coverage, the power consumed, the economy of the base stations on the network and number of users connected. The growth in the coverage curve from generation to generation to get up to 82.04% reflects the generational increase in the service offer of the system in the area of interest. At the same time, the covered traffic rate is increased to around 100%. The power consumed as well as the number of sites rise in the same way from generation to generation in order to densify the area of interest with the aim of improving the traffic coverage. However, the reduction of energy consumption is obtained through the reduction of the number of sites and the adjustment of the power of each installed site. The application of the proposed algorithm leads to an average site reduction rate of 42% as well as a reduction in energy consumption of the retained sites of around 2.4%. Notwithstanding a certain alteration in the coverage is due to the contradictory nature of the objectives, it follows generally from the above that the approach used optimizes the number of sites and the total energy consumption, thus contributing not only to the reduction of capital expenditure but also to the reduction of the exposure to electromagnetic radiation.

9. Conclusion

In all of the above, we have formulated a mathematical model, followed by a genetic algorithm to solve the migration problem of an existing network to a new generation network. This algorithm has generally led to the reduction of the sites to be deployed as well as the reduction of the energy consumption of the resulting network while connecting the maximum number of users. These two components contribute not only to the reduction of capital expenditure and operational expenditure, but also to the reduction of the electromagnetic radiation exposure of users and therefore to the promotion of green networks.

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