IEEE 802.11 Network Planning based on ESBEA Evolutionary Algorithm to Improve Location Accuracy

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***Abstract*— The main problem of radio planning is motivated by the overall goal of improving the performance of current communications services. Whatever the base station nature, these tools will need to transmit data as quickly as possible while ensuring reception, minimizing information loss and offering a guarantee of the continuity of service. If planning has covered different domains such as minimizing the cost or improving the signal reception, the upgrade of the positioning quality is rarely discussed. In this paper we propose a planning algorithm aiming to help place the APs in such a way as to give the user accuracy under a threshold no matter where his location. The principle is based on the idea that, to improve the accuracy, we must have at least four transmitters well distributed in space in order to estimate the user's position. To appreciate the geometric distribution of the transmitters, we basically use the Geometric Dilution Of Precision criteria. Indeed, we try to place the APs in such a way that the user will have at least four well-distributed APs for each (x,y,z). The idea of our planning algorithm is based on placing the APs so that we have a GDOP of 1 to 3 for each (x,y,z). Indeed, instead of talking about improving the accuracy of the user positioning, we aim to minimize the GDOP's value by using an evolutionary algorithm. In this case we use ESBEA. ESBEA is a multi-objective evolutionary algorithm using a simulated binary encoding. The multi-objective aspect can handle problems for which several evaluation criteria, though often conflicting, are needed. The simulation tests establish good prospects for our scheduling algorithm. Indeed, they have proved effective when it comes to placing the transmitters so that the user can obtain an estimate of its position with the least possible error.**

Keywords- Planning, GDOP, GPS, Wi-Fi, positioning, evolutionary algorithm.

I. INTRODUCTION

The main problem of radio planning is motivated by the overall goal of improving the performance of current communications services. Whatever the base station nature, these tools will need to transmit data as quickly as possible while ensuring reception, minimizing information loss and offering a guaranty of the continuity of service. The difference between wireless technologies and wired technologies depends on the nature of their communications channel, which does not limit losses, but forms an unlimited fluid. The nature and the reflection properties of the environment where the medium is located are an influential factor in the behaviour of its transmission. Indeed, the medium is located in an open environment, which means that the radio wave propagation obeys to the phenomena of reflection, refraction, diffraction and interference that occur locally. These random factors limit the performance of wireless transmission technologies in terms of communications range and transmission quality.

The main criterion that allows radio communication to be established is only the fact that the ratio of the power received signal and the surrounding noise must be sufficient to allow the receiver demodulation signal. Because of the nature of the radio medium, it is difficult to obtain quality communication similar to those achieved with wired technologies.

The aim of every communication and transmission system, whether wired or not, is to reach its nominal or optimal performance regardless of the nature of the environment in which it is deployed. In order to achieve this goal, it is necessary to study and respect the constraints inherent to the operability of every transmission system. In the case of wireless networks, more complex constraints must be managed if we tend to achieve optimal transmission conditions. Among these constraints, we find the pattern and nature of the environment (position and nature of walls, presence of furniture, movement of people...) that is one factor the link quality depends on which plays an essential role for the good reception of the message.

Based on this reasoning, it is clear that the choice of the location and characteristics of radio issuers, with a given description of the environment, is essential for the proper functioning of a wireless network. This choice is the heart of the problem of radio planning addressed in this chapter.

Planning wireless network is an optimization problem where the decision variables are given by all the configuration parameters of the access points and the objective is to optimize a mathematical description of service quality.

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II. RELATED WORK

Most of the models studying sizing and planning show that only access points are causing interference. But if one wants to have a better estimate of the user's position using signal strength, we must take into account the mobile station [6]. Indeed, to locate a mobile station, the environment radio control of a building is required. Every attempt to locate the signal strength received by the AP at the current point is searched in the database to deduce the position of the receiver [7]. It is also important to stress the importance of AP placement for applications such as providing location services [8]. Work that reflects the position of access points to improve the accuracy of estimating the position of the station is proposed in [9] by Chu et al. and in[10].

In [9] Chu et al. propose a model that treats the positioning. The authors introduce the quality of a positioning procedure as one of the planning objectives. Thus, a localization procedure, which operates the intersection of AP service areas, is proposed. The location of the mobile station is set up according to the identifier of all APs that the station picks. This identifier allows determining a portion of the plan. In addition, the authors use the simulated annealing (SA) method to determine the locations and transmission ranges of base stations in order to achieve the best possible positioning accuracy.

The more partitioned into a large number of portions the plan is, the more accurate the location.

III. ACCURACY ESTIMATION CRITERIA

A. GDOP

The final positional accuracy of a point determined using absolute GNSS survey techniques is directly related to the geometric distribution of satellites observed during the survey session.

The formula [11] expressing the geometrical ambiguities affecting the GNSS final positioning accuracy resulting from satellite configuration geometry is called the Geometric Dilution Of Precision (GDOP).

Let consider the satellites distribution as a set of distances between each satellite and the user. Indeed the absolute distance between the user and the satellite can be formulated as following:

$$R_i = \rho_i + \Delta\rho_i^{iono} + \Delta\rho_i^{trop} \quad (1)$$

where ρ_i is called the ith satellite pseudo-range and is expressed as following:

$$\rho_i = \sqrt{(x_{sat}^i - x_u)^2 + (y_{sat}^i - y_u)^2 + (z_{sat}^i - z_u)^2} + \delta t_u \quad (2)$$

$i \in [1, N_{sat}]$ is the identifier of the visible satellite, N_{sat} the number of visible satellites and u means the user; $\Delta\rho_i^{iono}$ and $\Delta\rho_i^{trop}$ are calculated from a model (They range from empirical models like IRI95 and PIM which capture large scale climatologically behaviour from historical data to real-time estimators that reconstruct the ionosphere and troposphere ionization in specific areas). $(x_u, y_u, z_u, \delta t_u)$ are considered the four unknown system variables and δt_u is the correction the receiver has to apply to its own clock.

To solve this system we need four equations, which mean four pseudo-ranges, from four different satellites.

If we apply the Taylor expansion to the pseudo-range we obtain at the first order $\Delta\rho_i$ (see Equation (3)).

$$\Delta\rho_i = \rho_i - \hat{\rho}_i = a_{xi}\Delta_{xu} + a_{yi}\Delta_{yu} + a_{zi}\Delta_{zu} - c\Delta t_u \quad (3)$$

where $\hat{\rho}_i$ is the itth pseudo-range estimation.

The geometry matrix H is:

$$H = \begin{pmatrix} a_{x1} & a_{y1} & a_{z1} & 1 \\ a_{x2} & a_{y2} & a_{z2} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ a_{xN_{sat}} & a_{yN_{sat}} & a_{zN_{sat}} & 1 \end{pmatrix} \quad (1)$$

where:

$$a_{xi} = \frac{x_{sat}^i - \hat{x}_u}{\hat{r}_i}$$

$$a_{yi} = \frac{y_{sat}^i - \hat{y}_u}{\hat{r}_i}$$

$$a_{zi} = \frac{z_{sat}^i - \hat{z}_u}{\hat{r}_i}$$

and

$$\hat{r}_i = \sqrt{(x_{sat}^i - \hat{x}_u)^2 + (y_{sat}^i - \hat{y}_u)^2 + (z_{sat}^i - \hat{z}_u)^2}$$

$\hat{x}_u$, $\hat{y}_u$, $\hat{z}_u$ are the estimated user coordinates.

The H matrix can also be expressed by using the azimuth Az_i and the elevation E_i

Let us define the covariance matrix G as following:

$$G = (H^T H)^{-1} = \begin{pmatrix} \sigma_x & & & \\ & \sigma_y & & \\ & & \sigma_z & \\ & & & \sigma_t \end{pmatrix} \quad (5)$$

The GDOP is a scalar, dimensionless quantity used in an expression of the positioning accuracy ratio. It is the ratio of the standard deviation of one coordinate to the measurement accuracy.

The standard deviation shows how much variation or "dispersion" there is from the "average" (mean or expected/budgeted value).

Let assume that σ_R is the overall standard deviation in range in meters.

The GDOP values are a function of the diagonal elements of the covariance matrices of the adjusted parameters of the observed GPS signal. In fact, The GDOP is defined as the square root of the sum of estimate position and time error variances.

Indeed, the GDOP's formula is as following:

$$GDOP = \frac{\sqrt{trace(G)}}{\sigma_R} \quad (6)$$

Where trace is the summation of the matrix diagonal elements. In general, the more satellites can be observed and used in the final solution, the better the solution. The GDOP can also be used to select four satellites in a particular constellation that will provide the best solution. Satellites spread around the horizon will provide the best horizontal accuracy, but the weakest vertical elevation. The smaller is the GDOP, the more accurate is the position.

Similarly to the context of GPS, the Cramér-Rao Bound has been proposed as a criterion to censor ineffective links/nodes.

B. Hybrid/Combined GDOP

As we have seen in previous sections, the standalone positioning systems became incapable to provide accurate position estimation in all the situations and in all the environments.

The operators offer more and more hybrid positioning systems. But if we have a coefficient that is the GDOP for GPS and CRB for wireless networks that helps to appreciate the accuracy degree for those positioning systems, in this section we will try to propose an indicator for systems based on combining GPS and Wi-Fi signals.

Let assume N_{AP} and N_{sat} the number of visible access points (AP) and visible satellites respectively.

The distances between user and the APs are expressed as following:

$$\begin{cases} d_1 = \sqrt{(x_{AP}^1 - x_u)^2 + (y_{AP}^1 - y_u)^2 + (z_{AP}^1 - z_u)^2} \\ d_2 = \sqrt{(x_{AP}^2 - x_u)^2 + (y_{AP}^2 - y_u)^2 + (z_{AP}^2 - z_u)^2} \\ \vdots \\ d_{N_{AP}} = \sqrt{(x_{AP}^{N_{AP}} - x_u)^2 + (y_{AP}^{N_{AP}} - y_u)^2 + (z_{AP}^{N_{AP}} - z_u)^2} \end{cases} \quad (7)$$

Applying the Taylor expansion at the first order we obtain:

$$\Delta\rho_i = \rho_i - \hat{\rho}_i = b_{xi}\Delta_{xu} + a_{yi}\Delta_{yu} + a_{zi}\Delta_{zu} \quad (8)$$

where $i \in [1, N_{AP}]$.

We define the geometry matrix H_{AP} as bellow:

$$H_{AP} = \begin{pmatrix} b_{1x} & b_{1y} & b_{1z} \\ b_{2,x} & b_{2y} & b_{2z} \\ \vdots & \vdots & \vdots \\ b_{N_{AP},x} & b_{N_{AP},y} & b_{N_{AP},z} \end{pmatrix} \quad (9)$$

where

$$b_{xi} = \frac{x_{AP}^i - \hat{x}_u}{\hat{r}_i}$$

$$b_{yi} = \frac{y_{AP}^i - \hat{y}_u}{\hat{r}_i}$$

$$b_{zi} = \frac{z_{AP}^i - \hat{z}_u}{\hat{r}_i}$$

and

$$\hat{r}_i = \sqrt{(x_{AP}^i - \hat{x}_u)^2 + (y_{AP}^i - \hat{y}_u)^2 + (z_{AP}^i - \hat{z}_u)^2}$$

The pseudo-ranges between user and the satellites are as bellow:

$$\begin{cases} \rho_1 = \sqrt{(x_{sat}^1 - x_u)^2 + (y_{sat}^1 - y_u)^2 + (z_{sat}^1 - z_u)^2} + \delta t_u \\ \rho_2 = \sqrt{(x_{sat}^2 - x_u)^2 + (y_{sat}^2 - y_u)^2 + (z_{sat}^2 - z_u)^2} + \delta t_u \\ \vdots \\ \rho_{N_{sat}} = \sqrt{(x_{sat}^{N_{sat}} - x_u)^2 + (y_{sat}^{N_{sat}} - y_u)^2 + (z_{sat}^{N_{sat}} - z_u)^2} + \delta t_u \end{cases} \quad (10)$$

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Based on equation 4 the geometry matrix H_{sat} is:

$$H = \begin{pmatrix} a_{x1} & a_{y1} & a_{z1} & 1 \\ a_{x2} & a_{y2} & a_{z2} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ a_{xN_{sat}} & a_{yN_{sat}} & a_{zN_{sat}} & 1 \end{pmatrix}$$

The H_c matrix for a hybrid/combined positioning system based on GNSS and Wi-Fi is:

$$H_c = \begin{pmatrix} H_{sat} \\ H_{AP} \end{pmatrix} \qquad (11)$$

$$H_c = \begin{pmatrix} a_{x1} & a_{y1} & a_{z1} & 1 \\ a_{x2} & a_{y2} & a_{z2} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ a_{xN_{sat}} & a_{yN_{sat}} & a_{zN_{sat}} & 1 \\ b_{x1} & b_{y1} & b_{z1} & 0 \\ b_{x2} & b_{y2} & b_{z2} & 0 \\ \vdots & \vdots & \vdots & \vdots \\ b_{xN_{AP}} & b_{yN_{AP}} & b_{zN_{AP}} & 0 \end{pmatrix} \qquad (12)$$

The covariance matrix G_c is:

$$G_c = (H_c^T H_c)^{-1}$$

And the GDOP for combined/hybrid positioning systems is:

$$GDOP = \sqrt{trace(G_c)} \qquad (13)$$

IV. SERVICE POSITIONING SIZING USING GDOP

The main idea of the proposed sizing algorithm is based on the key element of improving the accuracy that is the well geometrical distribution in space of at least four transmitters in order to estimate the user's position.

To appreciate the geometric distribution of the transmitters, basically we use the GDOP criteria. Indeed, we try to place the Access Points (AP) in such a way that the user will have, at each possible future location (x, y, z), at least four APs well distributed.

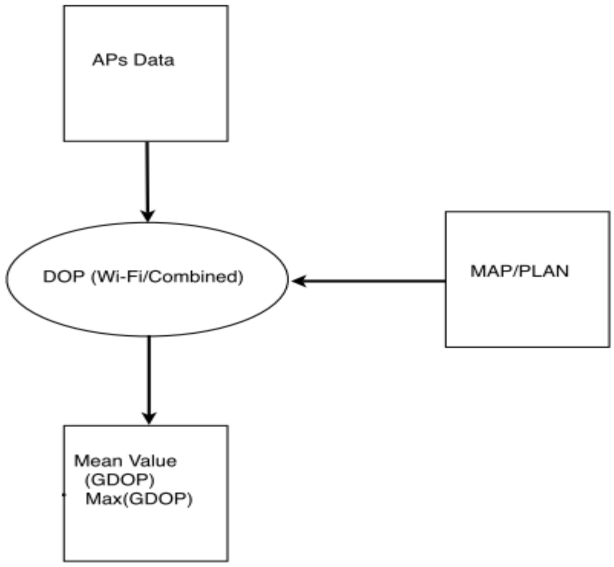

Figure 1. The sizing of the service positioning algorithm principle

A. *Networks Sizing for WiFi positioning system*

Let us consider how to arrange the APs coordinates such as the positioning accuracy is optimized and the coverage maximized. In fact, the aim of our work is to make the estimation of mobile terminal (MT) location more reliable and more available anywhere, at anytime. Indeed, the goal of this study is no matter where the user is located, one must ensure that its accuracy is acceptable and does not exceed a particular threshold. For, our sizing algorithm, we use homogeneous hardware with omnidirectional antenna so that we don't care about the antenna parameter and the hardware optimization.

We have already seen in the previous section that we can assess the accuracy of the user by calculating a factor called GDOP. The GDOP gives an overview about the accuracy degree. This one is highly related to the geometry of the APs. In fact, the AP alignments are bad accuracy companions. Basically, if the GDOP is of 1 to 2, we consider the position estimation with a high accuracy. In our case we use the GDOP suited for WLAN.

The idea of our planning algorithm (see Figure 1) is to place the APs so that at each (x, y, z) we have a GDOP of 1 to 3. Indeed, instead of talking about improving the accuracy to the user positioning, we aim to minimize the GDOP value.

The first step of the sizing algorithm consists of choosing the random APs coordinates.

The area to be sized is modelled by a grid matrix where each entry represents a square area of 0.1 meter by 0.1 meter. At each point (x, y, z) of the grid, we calculate the GDOP. We sum all GDOPs values. The sizing algorithm goal is to optimize the mean and the max GDOP which is as follows:

$$\sum_{i=0}^{L}\sum_{j=0}^{l} \mathrm{GDOP}(i,\ j)/(l * L) \qquad (14)$$

where L is the area width and l is the area length.

The optimum we tend to attend is that each GDOPi,j is under 3. If the mean is optimal, we consider that our planning is adequate; otherwise we change all the APs positions. Once we have the new APs coordinates we calculate again the GDOP's mean. We repeat the process until reaching our goal.
In order to avoid infinite loop, before starting sizing we fixe the number of iterations that our algorithm will turn up to find the right position for APs.

B. Networks Sizing for multi-standards positioning system

Nowadays, applications of combined and hybrid-positioning applications continue to appear. The user, quite often, finds himself in situations where there are only 2 APs (maybe less) in sight. Those situations do not allow him to calculate its position. For this reason, resort to hybridization or a combination of positioning systems is the best solution. In order to improve the accuracy, this paper proposes a planning algorithm (see Figure 2) for combined positioning systems, based on the same principle as the AP networks. As already mentioned in the previous subsection, the GDOP is used to assess the accuracy of the estimated position. For our algorithm we use the combined GDOP that uses data from at least one positioning system in order to estimate the accuracy. The main idea of our planning algorithm is to place the APs in such manner that combined with the satellites can provide optimal GDOP for the user.

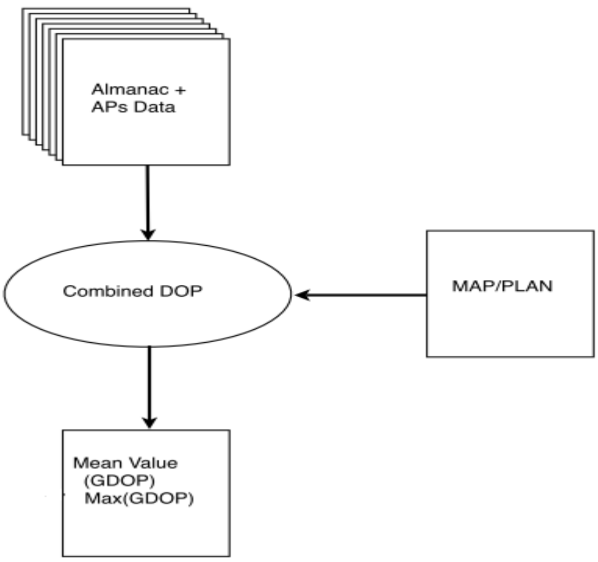

Figure 2. Multi-standards sizing algorithm

Both in WiFi positioning system and multi-standards positioning system, finding the positions of APs, which provide a good accuracy, is difficult. This requires the use of the optimization methods. This paper proposes an approach that uses an evolutionary algorithm. This type of optimization methods will be presented in the next section. The principle of genetic algorithms will be especially detailed.

V. EVOLUTIONARY ALGORITHMS

Evolutionary algorithms (EAs) are part of optimization methods inspired by biological evolution. They draw an analogy between the solutions of an optimization problem and individuals in nature. EAs are based on the principle that in the nature, the individuals that best fit to the environment have good chance to survive and to reproduce and the characters of parents are transmitted to their descendants. The EAs are metaheuristics or stochastic optimization methods for finding a solution i.e. a set of solutions approximating the optimal solution(s). Unlike exact methods, EAs do not guarantee to get the optimal solution but they can get a good solution in a humanly acceptable time.

The EAs are divided into several methods, including genetic algorithms [1,2]. The latter are considered as the most popular evolutionary algorithms [3].

A. Working principles of a basic genetic algorithm

Genetic algorithms (GAs) iteratively run a set of operations shown in Fig. 3.

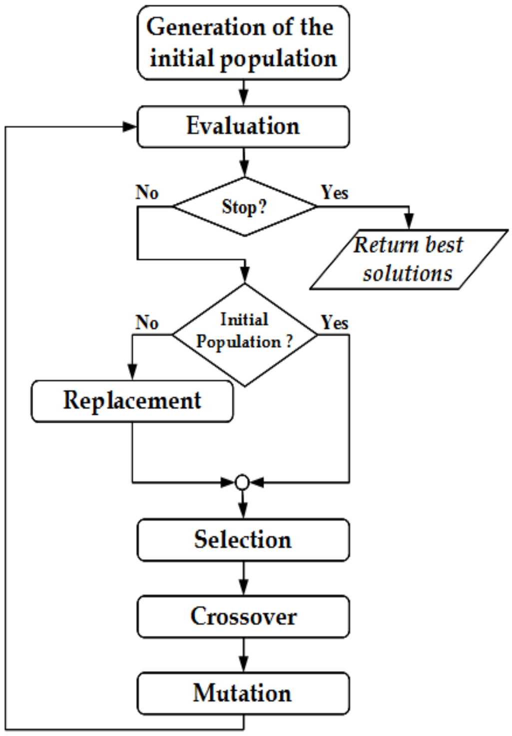

Figure 3. Flowchart of a basic genetic algorithm

The candidate solutions are called individuals and the set of solution is called population.

The first step is to generate a set of solutions to form the initial population. These solutions are usually randomly generated. Afterwards, the solutions are evaluated and the GA assigns fitness to each solution depending on its quality. According to their fitness, the solutions are selected for the recombination step (to generate new solutions, called offspring solutions). The probability to select a solution is proportional to its fitness. Hence, the best solutions are most likely to become parents. By analogy with natural selection and reproduction, offspring inherit qualities from their parents.

The recombination step consists of crossover and mutation operations. The crossover allows the GA to generate new solutions from two (or more) parents. The 1-point crossover is one of the usual crossover operators. A cut-off point is chosen randomly and the characters of children are alternately copied from parent 1 and parent 2 (see Fig. 4).

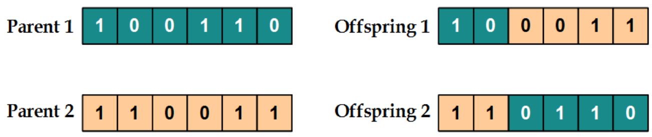

Figure 4. Example of a 1-point crossover

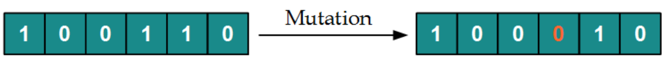

Figure 5. Example of a uniform mutation

During the mutation step, the GA can change one (or more) character of an individual. This allows the algorithm to better explore the search space. Fig. 5 shows an example of a uniform mutation

The reproduction enables the GA to generate new solutions. To control the size of the population, some solutions must be eliminated. This is the replacement step. It can favor offspring solutions, the best solutions among parents and offspring, or a combination of these two options.

All these operations (evaluation, selection, crossover, mutation and replacement) are repeated until a stopping condition is met. It may be a number of evaluated solutions.

To address the problem of Wi-Fi planning, an Elitist Simulated Binary Evolutionary Algorithm (ESBEA) [4] is used in this paper.

B. *ESBEA*

ESBEA encodes the candidate solutions of the optimization problem by a binary strings corresponding to the concatenation of binary representations of the decision variables of the problem. This representation is called the simulated binary encoding. It has the advantage of dealing with problems with integer and real-valued variables or a combination these two types. This method enables to easily encode the values of the variables. Besides, it permits to adjust the precision for real-valued parameters.

ESBEA also handles multi-objective problems. However, many real-world problems consist of several objectives. Moreover, these objectives are often conflicting, i.e. the fulfilment of one of them comes to the detriment of one or several others. Solving multi-objective problems usually leads to several compromise solutions. ESBEA solution uses a ranking strategy based on the Pareto dominance [5]. In addition, it builds several Pareto front and uses a selection method that enables the algorithm to avoid a premature convergence.

VI. OPTIMIZATION METHODOLOGY

The proposed approach is based on three main modules: an optimization engine (ESBEA), an IEEE 802.11 network planning simulator and a log analyzer. These three sub-systems cooperate to determine the best average and maximum GDOP in different given environments. Fig. 6 illustrates these modules and their interactions. Firstly, the ESBEA generates a set of possible solutions (the coordinates of all the APs) and transmits them to the simulator (the sizing of the service positioning algorithm). The latter Matlab code determines the GDOP obtained every one-decimetre in the building and then identifies the maximum and the average GDOP. Then a log files is generated. These files contain information about the location accuracy. The log files are passed to the third sub-system (log analyzer) that extracts the values of the objective functions. Then the calculated objective values are sent to the optimization engine, so that ESBEA can rank the solutions according to these values. The optimization tool runs some operations (selection, crossover, mutation, etc.) to regenerate another set of possible solutions that have to be simulated. The loop starts again, until the stop condition is met (a given number of solution evaluations).

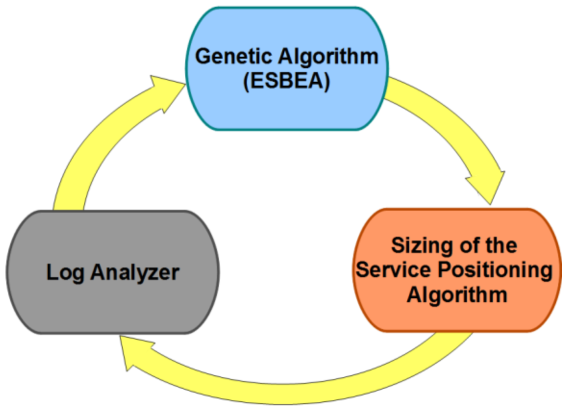

Figure 6. Optimization methodology

VII. SIMULATION RESULTS

Simulation was done using Matlab. The covering area is a square of 50 meters over 50 meters. We divided our covering area into a grid of small squares of 0.1m x 0.1m to obtain a graph whose axes are x and y.

We consider that each AP covers an area of about 2500m^2. At every point (x, y) of the covered area we generate a set of visible satellites at this point.

X1	Y1	X2	Y2	...	Xn	Yn

Figure 7. Sizing solution structure for n APs

TABLE I. WI-FI SIZING RESULTS BASED ON ESBEA

X1	Y1	X2	Y2	X3	Y3	X4	Y4	Mean GDOP	MAX GDOP
50.0	15.36203	4.30528	6.94716	48.43444	47.94520	15.55772	49.51076	1.48185	1.75211
49.11937	33.26810	19.27592	0.58708	32.58317	49.41291	1.07632	15.45988	1.49038	1.67631
49.21722	32.87671	23.18982	1.076320	29.64774	49.70645	0.68493	18.39530	1.48680	1.70071
50.0	15.36203	1.17416	6.75146	49.21722	48.23874	12.62230	49.70645	1.48360	1.74443
48.92367	16.63405	2.25048	3.81604	49.11937	50.0	12.62230	49.41291	1.48109	1.75562
49.70645	15.85127	0.68493	3.52250	49.51076	1.48062	14.57925	49.90215	1.48005	1.80885
49.31506	12.72015	8.80626	2.15264	49.80430	49.60861	15.65557	49.70645	1.48302	1.74947
50.0	28.66927	10.07827	0.09784	39.23679	49.90215	0.88062	20.35225	1.50100	1.65739
50.0	25.53816	9.88258	0.09784	37.86692	49.90215	0.88062	20.35225	1.49506	1.65970
49.80430	15.85127	0.68493	5.87084	49.51076	49.80430	14.09001	49.70645	1.48012	1.78306
49.80430	14.57925	4.30528	6.75146	49.119373	50.0	18.88454	49.02152	1.48075	1.764605
49.21722	34.83365	20.058708	0.19569	30.23483	49.21722	0.88062	14.09001	1.49045	1.67379
49.02152	14.57925	4.79452	6.55577	49.60861	49.80430	19.17808	49.51076	1.48062	1.77677

Length = 50m
Width = 50m

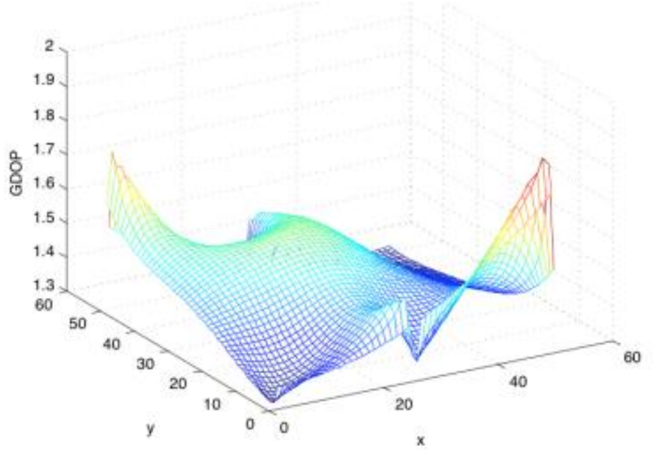

Figure 8. AP1 = (0, 0, 0) ; AP2 = (0, 25, 0) ; AP3 = (0, 50, 0) ; AP4=(50, 0, 0) ; AP5 = (50,25, 0); Mean(GDOP) = 1.45; Max(GDOP) = 1.80

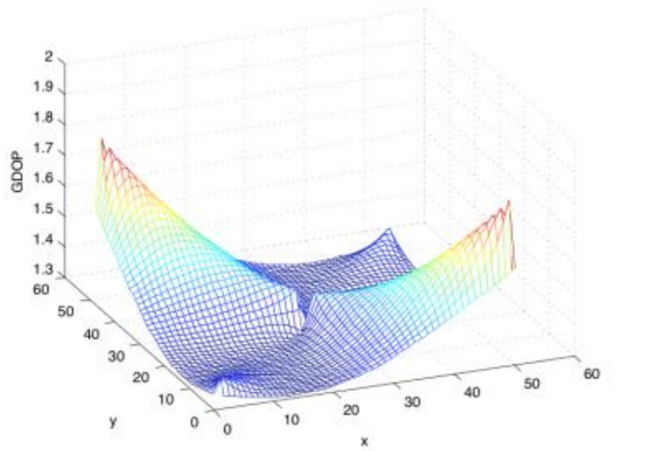

Figure 9. AP1 = (0, 0, 0) ; AP2 = (0, 50, 0) ; AP3 = (25, 25, 0) ; AP4 = (50, 0, 0) ; AP5 = (50,50, 0); Mean(GDOP) = 1.41; Max(GDOP) = inf

For our problem, the solution provided by ESBEA is a vector containing the coordinates of access points (see Figure 7).

Two evaluation criteria are used:

- The average GDOP calculated for the configuration proposed by the solution;
- The maximum GDOP calculated using this configuration.

The genetic algorithm parameters are:

- Size of the population: 60;

Number of evaluation: 20 000.

Two sets of simulations were carried on. The first set of simulations concerns the Wi-Fi network sizing. The second set concerns a combined positioning system based on Wi-Fi and GPS.

Figure 8 shows that this planning configuration leaves a gap in accuracy. Indeed, we note in the region where $x \geqslant 50$ and $y \geqslant 50$ the value of GDOP reaches important values, while the configuration of Figure 9 allows us to tend to a more homogeneous accuracy.

If one addresses the optimization of cost and therefore reduce the number of APs, we note that the configuration of Figure 10 is more appropriate to have a fairly balanced accuracy over the entire covered area, while Figures 11 and 12 show a gap in the accuracy.

When a solution is associated with a single value, it is called mono-objective problem, when combined with several values, multi-objective problem (or multi-criteria). As we are in the latter case, one seeks a set of non-dominated solutions (the “Pareto front”) solutions among which we cannot decide whether a solution is better than another.

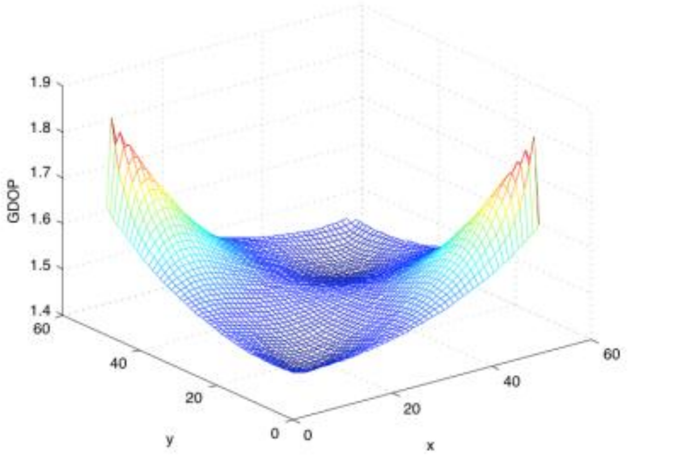

Figure 10. AP1 = (0, 0, 0) ; AP2 = (0, 50, 0) ; AP3 = (50, 0, 0) ; AP4 = (50, 50, 0); Mean(GDOP) = 1.53; Max(GDOP) = 1.83

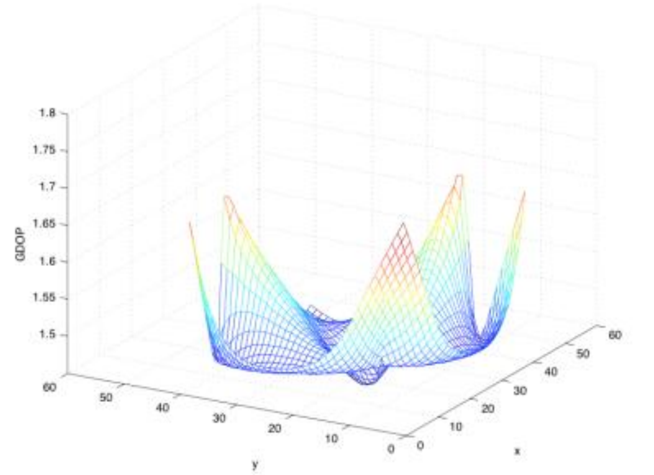

Figure 12. AP1=(10, 10, 0) ; AP2=(40, 10, 0) ; AP3=(10, 40, 0) ; AP4=(40, 40, 0); Mean(GDOP)=1.56; Max(GDOP)=2.39

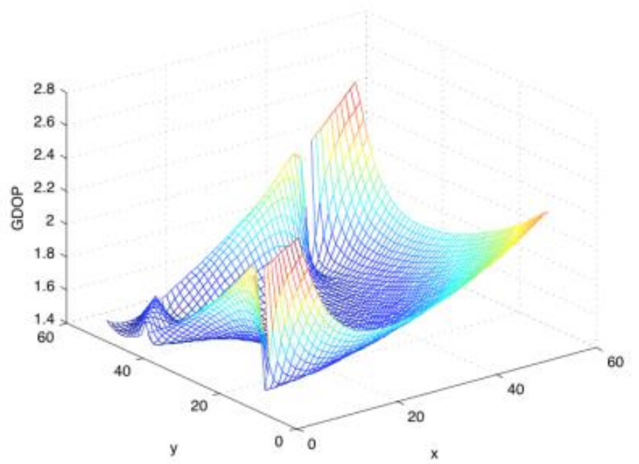

Figure 11. AP1 = (10, 0, 0) ; AP2 = (40, 0, 0) ; AP3 = (50, 10, 0) ; AP4 = (50, 40, 0); Mean(GDOP) = 1.65; Max(GDOP) = 2.39

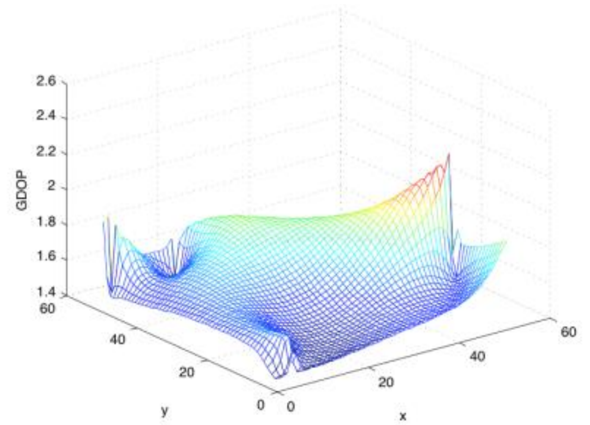

Figure 13. The lowest mean GDOP planning

TABLE II. COMBINED SIZING RESULTS BASED ON ESBEA

X1	Y1	X2	Y2	X3	Y3	X4	Y4	Mean GDOP	MAX GDOP
1.36986	1.07632	37.27984	0.0	0.09784	36.39921	37.47553	49.02152	1.64084	1.77012
0.0	0.88062	35.51859	0.19569	0.19569	37.47553	36.49706	49.60861	1.63893	1.77473
0.88062	0.78277	48.33659	17.31898	0.48923	37.67123	45.49902	49.90215	1.68419	1.76595
0.88062	0.78277	47.94520	17.22113	0.48923	37.57338	45.40117	49.80430	1.68299	1.76652
0.68493	0.29354	35.71428	0.88062	0.0	36.79060	33.56164	45.49902	1.63827	1.81110
0.39138	0.09784	35.12720	0.0	0.58708	34.93150	36.10567	47.06457	1.63740	1.81439
0.68493	0.29354	36.49706	0.88062	0.29354	36.59491	37.08414	45.59686	1.63877	1.79503

Length = 50m
Width = 50m

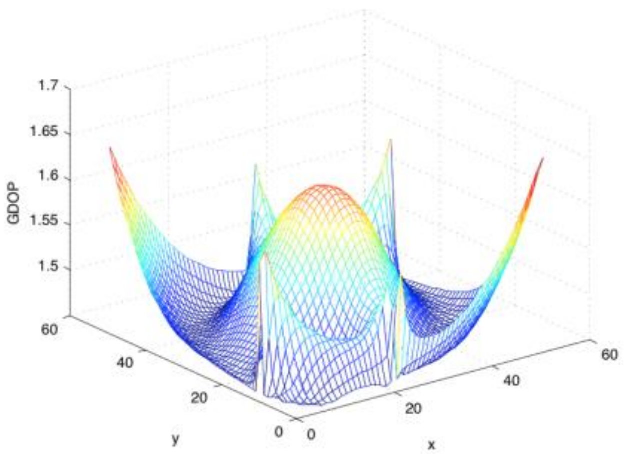

Figure 14. The lowest max GDOP planning

In our case, the aim is explicitly to find a set of optimal "satisfactory". The algorithm must then find all solutions of acceptable accuracy, not necessarily limited to single optimum. In fact, Table 1 shows the different configurations obtained. In Figures 13 and 14, we represent respectively the lowest mean GDOP and the lowest max GDOP distribution over the covered area. According to the user's needs, we choose the most appropriate planning configuration.

The Figure 15 synthesises the values of GDOP GPS obtained for a combined positioning system in a given environment where according to a specific area we have different number of satellites in view. We conclude that a part when we have four satellites in view, the GDOP goes to infinite.

Once we combine the GPS with the Wi-Fi by plotting the APs according to the satellite positions, the GDOP values becomes more compact and optimal as we can see in table 9.14.

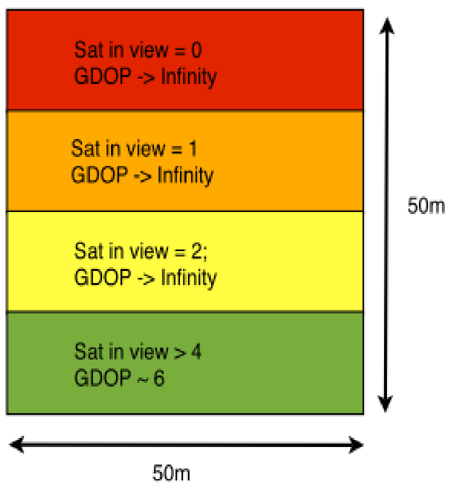

Figure 15. GPS standalone GDOP results

VIII. Conclusion

In this paper we have described the various stages necessary before the implementation of the inclusion of positioning accuracy in planning/sizing. Indeed, we consider planning for two types of positioning systems, a standalone and a combined system. These perspectives have led us to imagine and then propose two distinct algorithms. The first algorithm concerns sizing for Wi-Fi networks and the second one concerns sizing for the combined positioning systems based on Wi-Fi and GPS. The common link between these two algorithms is the calculation of the coefficient of DOP that we try to optimize in both cases.

During the simulation tests we have established good prospects for our scheduling algorithm. Indeed, it has proved effective when it comes to placing the transmitters so that the user can obtain an estimate of its position with the least possible error.

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