Layout of Routers in Mesh Networks with Evolutionary Techniques

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Abstract: Wireless Mesh Networks show cost-efficient and fast deployment characteristics, however their major problem is mesh router placement. Such optimal mesh router placement ensures desired network performance concerning network connectivity and coverage area. As the problem is NP hard, a motivation to solve the mesh router placement problem and seek optimal solution with suitable performance is to follow a heuristic approach using evolutionary techniques involving genetic algorithms including fuzzy aggregation. Two case studies are considered in this paper. The first one deals with a genetic algorithm application for spatial layout of routers in a two dimensional, obstacle free, wireless mesh network model. The second one considers a hybrid fuzzy-genetic scheme based on a fuzzy aggregation system that assesses the fitness of a genetic algorithm. The hybrid system carries out the routers layout evolution within an area with localization constraints where the placements of such routers are high cost. The results indicate the feasibility of the proposed method for this type of application.

1 INTRODUCTION

A wireless mesh network (WMN) can be seen as a communications network made up of radio nodes planned in a mesh topology. There are two types of nodes in WMNs: mesh routers and mesh clients. A group of mesh routers, connecting to each other wirelessly constitutes a backbone to serve a set of mesh clients. A few mesh routers with Internet connections act as Internet Gateways to pass on the traffic between the Internet and the WMN. Low cost design characteristics and fast set up of WMNs is that make them a cost-effective option to establish wireless Internet connectivity for mobile users at anytime and anywhere. These features mainly would be useful in developing regions or countries, decreasing costs of deployment and maintenance of wired Internet infrastructures. The good quality and operability of WMNs widely depends on placement of mesh routers nodes in the desired area to achieve network connectivity, stability and user coverage. The purpose is to seek an optimal and strong topology of the mesh network to allow desired services to clients. But, in a practical deployment of WMN the purely random node positioning may end up in poor performance WMN since the final placement could be far from optimal. Besides, real deployment of WMNs may need taking into account some restrictions and features of a specific geographic area and thus one require to seek different topologies for distributing mesh routers. As a matter of fact, node layout is a critical aspect in WMNs. The purpose of this paper is to deal with the mesh router placement issue. As such problem is NP hard, a motivation to solve the mesh router placement problem and seek optimal solution with suitable performance is to follow a heuristic approach using evolutionary techniques involving genetic algorithms including fuzzy aggregation. The positioning of routers in a mesh network is not a trivial problem. Several studies using computational intelligent systems for this purpose have been carried out by universities and research centers around the world. (Girgis et al., 2014) uses a genetic algorithm and simulated annealing in order to search for a low-cost WMN configuration with constraints and determine the number of used gateways.

(Rezaei et al., 2011) proposes a genetic algorithm in connection with circle packing problem techniques that consist in packing non-identical circles without overlap inside the smallest containing circle C. Their model maximizes network connectivity and coverage area.

(Praba and Rani, 2013) focus their interest on the efficient route construction of the networks. The efficient route can be constructed by choosing the

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best neighbor for transmitting the packets. Their method is designed for finding the route from the source to the destination nodes using minimum-hop count.

In this paper, we will use genetic algorithms to determine the location of routers in a mesh network in connection with evolutionary techniques associated with fuzzy aggregation methods. Details of the modeling are discussed in section 3.

This paper is organized in five sections. The second section describes the basics of mesh networks. Section three deals with the modeling of the problem followed by section four which discusses case studies in connection with the routers layout problem. Finally section five ends the paper with the conclusions.

2 MESH NETWORKS BASICS

Wireless Mesh Networks (WMN) can be considered self-configured and dynamically self-organized, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves. Wireless Mesh Networks have two types of nodes: routers and clients. Routers show minimal mobility and form the backbone of mesh networks. Multi-hop communication is employed in WMNs and the gateway/bridge functionalities in routers make possible the integration of WMNs with several existing wireless networks such as Internet, Wi-Fi, cellular, and so on. The structure of a mesh network resembles the structure of an ad hoc network, where all the nodes of the network are in the same hierarchy without a server that manages the whole network. Basically, a mesh network consists of nodes that use the offered service - the clients - and by nodes in charge of transmitting or passing on the information that will be served by network clients - the Access Points, or APs, also referred as routers. Routers have multiple network interfaces and communicate to maintain network connectivity. They have a small transmission power and, in general, use multihop technology, which transmits the desired information from AP to AP until it reaches the desired client. These routers have technology for transmitting on multiple radio channels and can be connected to other similar devices and are responsible for communicating the clients to the network. There are several models and manufacturers of mesh routers in the market, such as Google wifi, Deco M5 (TPLink), Eero, Lyra Trio (Asus), Orbi (Netgear), Luma and LinkSys Velop. Table 1 shows typical signal transmission power of routers from several manufacturers. Wireless mesh technology allows networks to be built in areas with large coverage, where conductive cables are difficult to install and in locations that are in an emergency situation. Three standards are usually adopted for wireless mesh networks - the IEEE 802.16a standard, which covers WiMAX networks, IEEE 802.11s, better known as Wi-Fi networks and IEEE 802.15.5, which correspond to ZigBee networks (Lee et al., 2006). A survey on WMNs can be found in (Benyamina et al., 2012). In recent years, a number of university campi and research centers around the world have developed and widely used mesh networks such as campus access networks by users residing in their vicinity. Examples of pilot mesh wireless mesh networks are ReMesh in Niterói / RJ-Brazil (Saade et al., 2007), RoofNet at MIT-USA, Google Mesh in California-USA, VMesh in Greece, MeshNet at UCSB-USA (Lundgren et al, 2006), Microsoft Mesh- USA, among others.

Table 1: Typical routers signal transmission power.

	Frequency	
Manufacturer	2,5 GHz	5GHz
Google WIFI	-46 dBm	- 38 dBm
ASUS	-41 dBm	-39 dBm
Luma	-57 dBm	-59 dBm
TPLink	-20 dBm	-23 dBm

Mesh networking technology is ideal for building community access networks, allowing Internet access for those who cannot afford the high costs of a traditional Digital Subscriber Line (DSL) or cable broadband connection. Because of this, another potential use of mesh networks is the construction of digital cities, providing wireless communication infrastructure in a metropolitan environment to all citizens, which has already been carried out in cities such as Dublin, Taipei, Pittsburgh and Philadelphia. Wireless mesh technology allows networks to be built in areas with large coverage, where conductive cables are difficult to install and in locations that are in an emergency situation. Three standards are usually adopted for wireless mesh networks - the IEEE 802.16a standard, which covers WiMAX networks, IEEE 802.11s, better known as Wi-Fi networks and IEEE 802.15.5, which correspond to ZigBee networks (Lee et al., 2006). A survey on WMNs can be found in (Benyamina et al., 2012). In recent years, a number of university campi and research centers around the world have developed and widely used mesh networks such as campus access networks by users residing in their vicinity. Examples of pilot mesh wireless mesh networks are ReMesh in Niterói / RJ-Brazil (Saade et al, 2007), RoofNet at MIT-USA, Google Mesh in California-USA, VMesh in Greece, MeshNet at UCSB-USA (Lundgren et al, 2006), Microsoft Mesh- USA, among others.

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- Composition
· Homogeneous: all routers have the same feature.
· Heterogeneous: composed of different routers.

- Organization
· Flat: networks without grouping.
· Hierarchical: networks with clusters

- Distribution
· Regular: nodes are evenly distributed in the monitoring area.
· Irregular: nodes are distributed randomly in the monitoring area.

The coverage area of a router is specified by the manufacturer and can be calculated as the area of a circle, where R is the coverage radius of the router, as shown in Figure 1a. Figure 1b shows an example of coverage area.

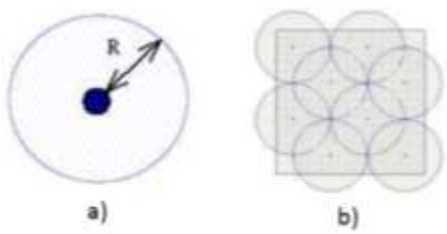

Figure 1: a) Coverage radius of a Router; b) Example of a coverage area.

Figure 2: (a) Routers in regular distribution; b) Routers in irregular distribution.

The coverage area is closely linked to the way the routers are distributed in the area. Figure 2 shows two examples of routing distribution in the coverage area.

3 PROPOSED MODEL

The core model used for solving the mesh router placement is based on genetic algorithms. The genetic algorithm (GA) is inspired by biological evolution, as it makes use of a selection of individuals, uses genetic operators and operates in a random and oriented way, seeking an optimal solution within a population. The main application of genetic algorithms is in optimization problems with very large or complex search spaces, which makes the use of traditional techniques unfeasible. In the case of the search method, a comparison is made between the evolution of the species and the problem in question a population of individuals (possible solutions) identified by chromosomes, are evaluated and associated with an aptitude and subjected to a process of evolution, through selection and reproduction, for several generations. Aptitude is the quality of its results, in relation to the transfer of aptitude, the crossing is modeled by an operator called crossover and adaptive modifications are modeled by mutation operators. Statistically, over several generations, the results tend to converge to the fittest results. The typical flowchart of a GA is shown in Figure 3.

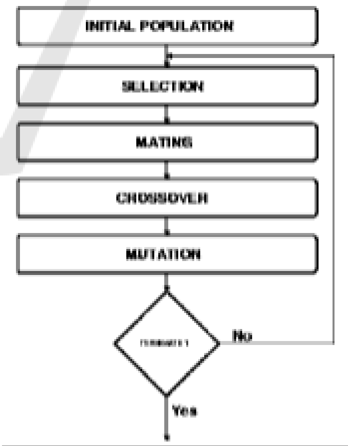

Figure 3: Typical flowchart of a Genetic Algorithm.

The objective or fitness function is defined based on the specification of the problem and is fundamental to a successful implementation. In general, the objective function involves only a single criterion. However, most of the real problems involve more than one objective to be considered, so the objective function must use methods for converting a measure of vector fitness into a scalar one(Davis, 1990).The general GA parameters influence its performance and can be used to establish a stopping criterion for executing the algorithm. Such parameters include population size, maximum number of generations and operator application rate. The choice of parameters must meet the established empirical criteria or the specific characteristics of the specific problem.

In order to carry out case studies with multiple objectives in genetic algorithms we can use fuzzy aggregation methods.

3.1 Fuzzy Aggregation Methods

The use of fuzzy systems makes it possible to simultaneously evaluate all the objectives, integrating the preferences of the user in relation to each objective and to each situation. This feature is a good advantage over Pareto optimality multi-objective methods, since it does not require user interference to choose the best solution at the end of the process, since preferences or specifications are inserted before evolution in a more simple and interpretable fashion through fuzzy logic and thus the process of evolution is guided in the direction of pre-established preferences. Each individual in the GA population represents a possible solution to the problem. During the evaluation process, individuals are applied to the function or model that describes the problem and the results obtained in relation to each objective are used as inputs to the fuzzy system. For each individual of the population the fuzzy aggregation method is applied yielding a single fitness value. Figure 4 illustrates the evaluation model using the Fuzzy Aggregation method. The rates of selection operations, crossover, mutation on the current population, population size and the maximum number of generations are defined by the designer before the start of the algorithm.

The evolution ends when a certain stop criterion is reached. The most frequent stopping criterion is specified by a certain maximum number of generations. Another possibility is to establish an aptitude value to be reached or stop the execution of the algorithm when there is no evolution for a certain number of generations. After the evaluation of all individuals of the current generation, the genetic algorithm continues the evolution process.

The fuzzy aggregation system has the normal operation of a fuzzy inference system. Each input of the system corresponds to an objective and the membership functions have triangular or trapezoidal

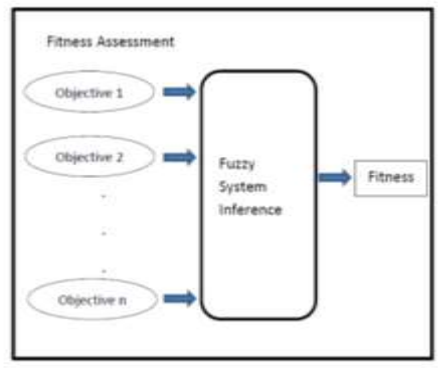

Figure 4: Evaluation model with Fuzzy aggregation.

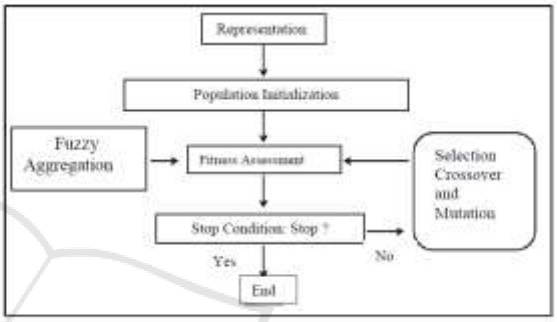

Figure 5: GA model with Fuzzy aggregation.

format. The genetic algorithm used in this paper follows the model presented in Figure 5 in the traditional way, until the evaluation of the next generation, where the evaluation process through the fuzzy aggregator is again executed for all individuals, until the stopping criterion is reached.

The rules of the fuzzy aggregator are elaborated in order to meet the preferences required for the problem considering each objective.

4 CASE STUDIES

The case studies considered in this paper consist of positioning routers for a mesh network to be used for data acquisition in an agricultural environment of size 50m x 50m. All use Matlab Fuzzy Toolbox.

The first study consists of using a traditional genetic algorithm, with a single objective. The goal is to position the routers so that each monitoring point in the field is covered by at least one router.

The second study considers that there are areas in the field with a higher installation cost. To do so, we discard areas of the field where the cost for the installation of routers is high. In this way the application uses a genetic algorithm together with a

Fuzzy aggregation method to carry out a multi-objective study where it is desired to position routers so that each monitoring point in the field coverage area must be in contact with at least one low cost router.

4.1 First Case Study

The environment of this first case study is an agricultural area of 2500m², where the spatial distribution of the routers must be carried out. In this environment it is necessary that each monitoring point reaches at least one router. The device responsible for monitoring has a range of 13 meters.

The organization of the routers is flat (no clustering), homogeneous (all routers have the same characteristic) and irregular. In order to achieve these objectives a traditional single-target genetic algorithm is used. The 16 monitoring points are positioned in the area, as shown in figure 6.

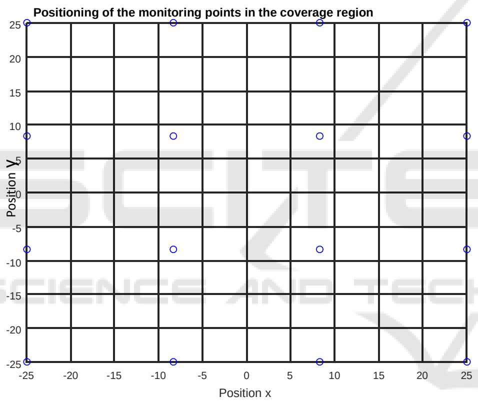

Figure 6: Monitoring points (16).

Several tests were carried out changing the values of the parameters of the genetic algorithm and it was observed that the parameters presented in table 2 below have met the expectations of solutions to the problem. Figure 7 shows the curve of the best individual and the average of the population. It can be noticed that the best individual reached the maximum aptitude around the 120th generation and the average followed this evolution.

Figure 8 shows the location of the monitoring points and the positioning of the routers for the best individual which was achieved by the GA.

The green square in figure 8 represents the area (50m x 50m), the smaller blue circles are the monitoring points and the larger blue circles represent the area each of the routers are covering, and the "x" in red are the routers.

Table 2: Parameters of the GA for case study 1.

Parameters	Values
Number of generations	200
Search Region	-25 25; -25 25
Precision	50 cm
Population	300 individuals
Fitness	Number of Monitoring Coverage points
Selection	Geometric Normalization of 5%
Crossover Rate	80%
Mutation Rate	1%

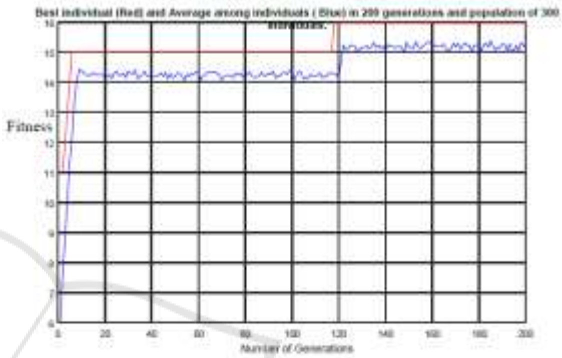

Figure 7: Best individual (Red) and average (Blue).

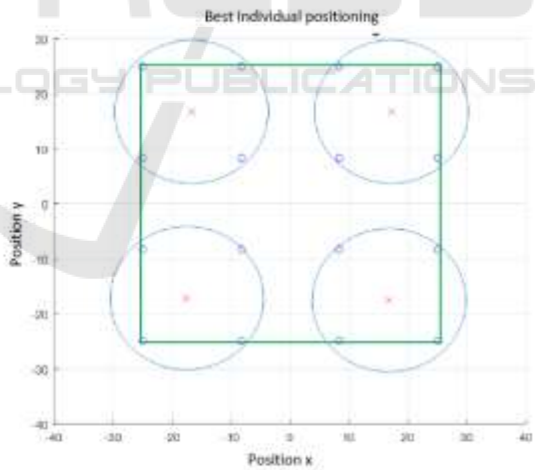

Figure 8: Best individual positioning for the first case study.

It can be seen that the routers were positioned meeting the established criterion, since each monitoring point is being covered by a router.

This first study did not take into account differences in the cost of installing the routers in relation to the most difficult access areas. Considering that cost is something that is important to be reduced in the majority of the projects, in mesh networks would not be different. Therefore, the proposal of the second case study is to carry out the configuration of the network taking into account the installation costs.

4.2 Second Case Study

One way to reduce the cost of a mesh network is to define the minimum amount of routers needed to cover an area without positioning routers in places where the cost of installation is high.

As in the first case study, the environment of this second case study is an agricultural area of 2500 m², where the spatial distribution of the routers must be carried out. The device responsible for the monitoring has a range of 13m and the organization of the routers is flat i.e. no grouping, homogeneous (all routers have the same characteristic) and irregular.

For this scenario it is necessary that:

• each monitoring point reaches at least one router;

• the routers are not positioned in places where the installation cost for them is high.

Therefore, we have a multi-objective problem: to cover the area and reduce costs.

To achieve these objectives a genetic algorithm is used together with a fuzzy aggregation scheme.

The developed fuzzy system is of Mamdani type, characterized by being simpler and more interpretable than TSK type systems, and all the rules have the same degree of importance, i.e., weights equal to one.

The fuzzy aggregation system has two inputs: "number of monitoring points served" and "cost". Its output is the "fitness" that receives an evaluation between 0 and 10. The defuzzification method is the average of the "maximums". Figure 9 shows the fuzzy aggregation parameters used in this case study.

Figure 10 shows the membership function of the input "Number of Monitoring Points Served".

Figure 11 illustrates the membership function of the cost.

In figure 12 one can see the membership function of the fuzzy aggregation system output fitness.

The rules of the Fuzzy Aggregator are as follows:

• 1. If (NumMPattended is low) and (Cost is low) then (Fitness is bad)

• 2. If (NumMPattended is low) and (Cost is medium) then (Fitness is bad)

• 3. If (NumMPattended is low) and (Cost is high) then (Fitness is bad)

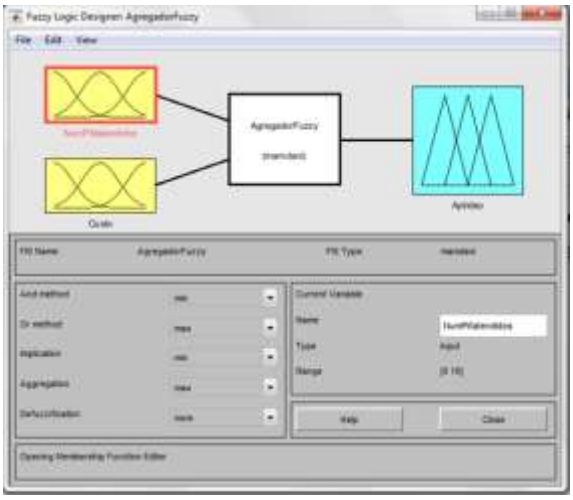

Figure 9: Fuzzy aggregation system parameters.

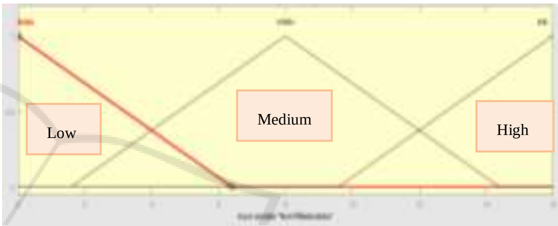

Figure 10: Membership function of the input - number of monitoring points served.

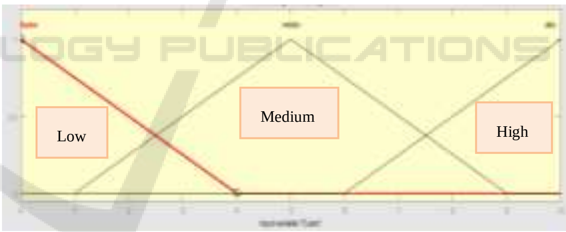

Figure 11: Membership function of the input - cost.

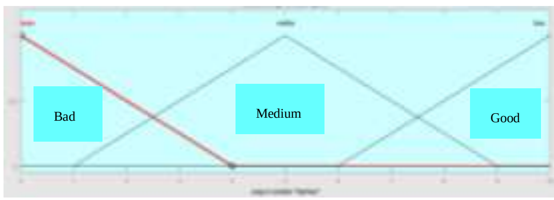

Figure 12: Membership function of the fuzzy aggregation system output - fitness.

• 4. If (NumMPattended is medium) and (Cost is low) then (Fitness is bad)

• 5. If (NumMPattended is medium) and (Cost is medium) then (Fitness is bad)

• 6. If (NumMPattended is medium) and (Cost is medium) then (Fitness is bad)

• 7. If (NumMPattended is high) and (Cost is low) then (Fitness is good)

• 8. If (NumMPattended is high) and (Cost is medium) then (Fitness is medium)

• 9. If (NumMPattended is high) and (Cost is high) then (Fitness is bad)

The parameter NumMPattended is the number of monitoring points attended.

Several tests were performed by changing the values of the parameters of the genetic algorithm and it was observed that the ones presented in table 3 have met the expectations of solutions to the problem.

Table 3: Parameters of GA for case study 2.

Parameters	Values
Number of generations	200
Search Region	-25 25; -25 25
Precision	50 cm
Population	300 individuals
Fitness	Fuzzy aggregation
Selection	Geometric Normalization of 5%
Crossover Rate	80%
Mutation Rate	1%

Figure 13 shows the area, the location of the monitoring points, and the high-cost installation regions of routers, regions in which the genetic algorithm should avoid positioning the routers.

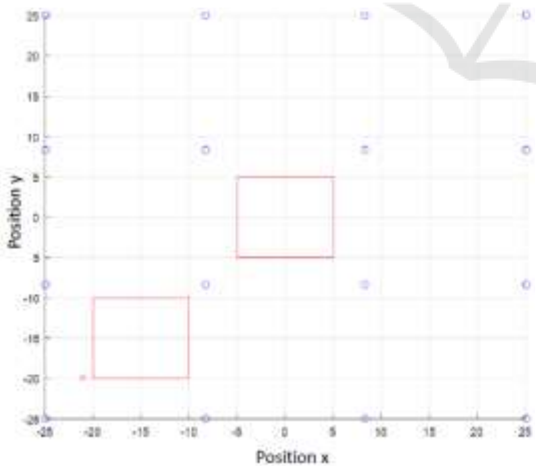

Figure 13: Monitoring points and high cost areas in red for case study 2.

Figure 14 shows the curve of the best individual and the mean of the population. From the graphs it can be seen that the best individual reached the maximum fitness around the 60th generation and the mean followed this evolution.

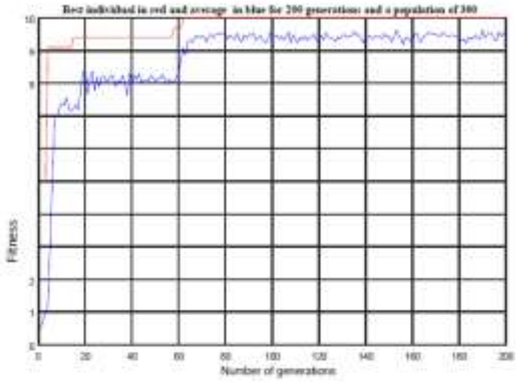

Figure 14: Best and average individual for case study 2.

Figure 15 shows the location of the monitoring points and the best positioning of the routers for case study 2.

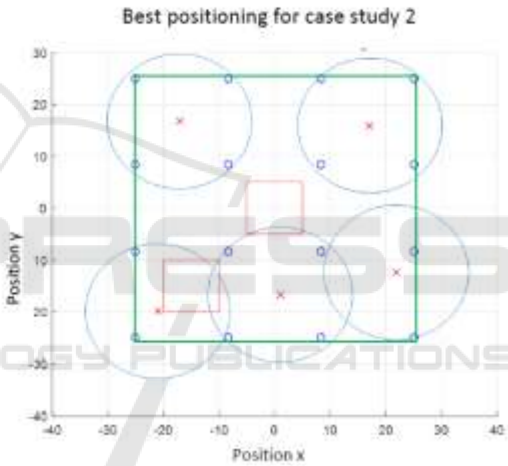

Figure 15: Best individual positioning for case study 2.

The green square of the figure 15 represents the coverage area (50m x 50m), the smaller blue circles are the monitoring points, the larger blue circles represent the area each of the routers are covering. The x in red are the routers and the squares in red are the regions of the area where the cost for installing routers is high. In the same figure it can be seen that the routers were positioned according to the established criteria, since each monitoring point is being covered by a router and no router was positioned in the area where the installation cost is high.

It can also be observed that, with the restriction of positioning of routers in areas of greater cost, it was necessary to use one more router to cover the area, yieldind five routers. Such additional cost of routers obviously must compensate for the installation of a router rather than higher cost.

The results obtained in the simulations fulfilled its objectives of determining the positioning of routers in mesh networks.

5 CONCLUSIONS AND FUTURE WORK

In this paper, two case studies were presented with applications in mesh networks, whose objective is the optimization of the positioning of routers in a field scenario with automation for data acquisition. In the first case study, with one variable, a genetic algorithm was used that resulted in satisfactory solutions. In the second case study, a fuzzy-genetic hybrid evolutionary technique was applied to a multi-objective problem, in which the cost variable was included in the routing question.

For future work in mesh networks it is expected the inclusion of new targets for the fuzzy aggregation system and possibly the design of a chromosome of variable size in the GA modeling may be investigated so that the evolution can also determine the number of routers suitable for the field coverage. A benchmark problem would be useful to compare different approaches and a way to interpret the results based on different objectives defined for each approach proposed by several researchers.

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