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A Genetic Approach Applied to the Setup of a Wireless Sensors Network to Monitoring a Location

Uma Abordagem Genética Aplicada à Configuração de uma Rede de Sensores sem Fio para Monitoramento de um Local

Marcelo Lisboa Rocha[1]

[1] DSc in Electrical Engineering. Postgraduate Program in Computational Modelling of Systems - UFT.

E-mail: mlisboa@uft.edu,br

ABSTRACT

This study presents a simulation of the configuration of a Wireless Sensor Network to cover a certain region. For this, a heuristic based on Genetic Algorithms is used. This heuristic takes into account the availability of various types of sensors, each with a cost and a range of action, as well as the use of electronic maps via WEB to specify an area by the user for monitoring. The goal is to position these sensors in such a way as to cover the entire specified area with the lowest possible cost. In this study, computational simulations are also performed that show the functioning of the proposed technique and the results obtained.

Keywords: Simulation. Wireless Sensors Network. Monitoring. Genetic Approach.

RESUMO

Este estudo apresenta uma simulação da configuração de uma Rede de Sensores Sem Fio para cobrir uma determinada região. Para isso, utiliza-se uma heurística baseada em Algoritmos Genéticos. Essa heurística leva em consideração a disponibilidade de vários tipos de sensores, cada um com um custo e um raio de atuação, bem como o uso de mapas eletrônicos via WEB para especificar uma área pelo usuário para monitoramento. O objetivo é posicionar esses sensores de forma a cobrir toda a área especificada com o menor custo possível. Neste estudo, também são realizadas simulações computacionais que demonstram o funcionamento da técnica proposta e os resultados obtidos.

Palavras-chave: Simulação. Rede de Sensores sem Fio. Monitoramento. Abordagem Genética.

1. INTRODUCTION

This study presents a simulation of the configuration of a Wireless Sensor Network (WSN) to cover a certain region. For this, a heuristic based on Genetic Algorithms (GA) is used. This heuristic takes into account the availability of various types of sensors (each with a cost and a sensing radius) in order to cover the entire specified region with the lowest possible cost.

Given the computational complexity of this problem that is NP-Hard (Nakamura, 2003), it is interesting to use heuristics to obtain good solutions in acceptable computational time. Meeting this need, this work presents a simulation proposal using a heuristic based on Genetic Algorithms (GA) for the configuration of a WSN for coverage (monitoring) of a region of interest with the lowest possible cost. In order to make the system interface more user-friendly, the Google Maps API was used, enabling the use of electronic maps, both for determining the area to be monitored and for visualizing the solution provided (choice and positioning of sensors) by the heuristic.

The rest of this work is organized as follows. In the second section there is the description of the problem addressed as well as about WSN. In the third and fourth sections there are respectively the details of the heuristic implemented and the computational simulations performed. Finally, in the fifth section there are the conclusions about the work developed and future works that can be done.

2. PROBLEM DESCRIPTION

The basic objective of WSN is to monitor a certain area/environment specified by the use of wireless sensors in order to meet all the demand points (sources where data are extracted) for later analysis and decision making.

Several applications focused on the monitoring area can be implemented using this technology (WSN) (Estrin et al., 2001). This is due to the need to monitor environments where human presence is not constant (or even inadequate), where cable passage is impractical and there are no energy sources, due to issues of accessibility, costs and risks (Tilak et al., 2002). Examples of such applications are: monitoring of inhospitable forest area, surveillance of a military region, monitoring disaster areas, sensing of chemically and/or biologically contaminated area among others (Akyildiz, Sankarasubramaniam and Cayirci, 2002) (DUMKA, A. et al, 2019).

The main functionalities of a WSN can be separated into five groups of activities, as proposed by Loureiro et al. (2003) and shown in Figure 1: configuration, maintenance, sensing, processing and communication. These phases can run concurrently or can be activated throughout the lifetime of the network. Each of these phases has a crucial function for the survival and functioning of the network. Figure 2 shows how to establish a WSN.

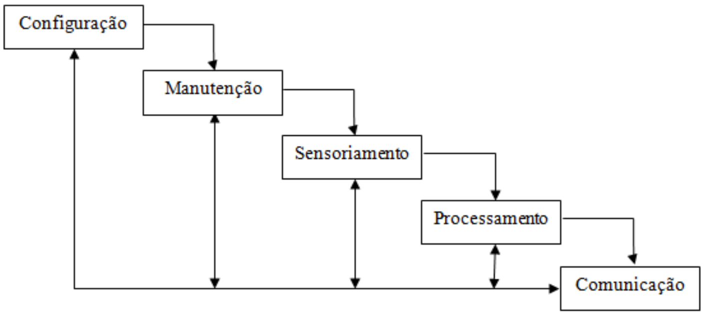

Figure 1. WSN life cycle [Loureiro et al., 2003].

As this work deals with the configuration phase, this will be the only one to be detailed. Further details of the other phases can be seen in Loureiro et al. (2003) and Nakamura (2003). The network configuration phase is where the nodes are established in the area to be monitored (they can be homogeneous or heterogeneous nodes). This configuration seeks to make the network meet all demand points in the monitored environment. To ensure full coverage of demand points, more than one sensor may monitor the same area.

Here, the demand points will coincide with the possible locations of a sensor. As a differential of this work in relation to others regarding the configuration phase of the WSN is that in previous works only one type of sensor is used and the possible locations for positioning are known. In this work, different types of sensors are used and their locations must be determined by the proposed heuristic.

Possible placement locations are determined as follows. The rectangle surrounding the area to be mapped is calculated, obtaining the smallest (minlat and minlong) and the largest (maxlat and maxlong) values for the latitude and longitude coordinates of the determined area. Considering the discretization size (minimum space between 2 possible placement locations) in Km (interval), the possible placement locations are determined according to the algorithm in Figure 3.

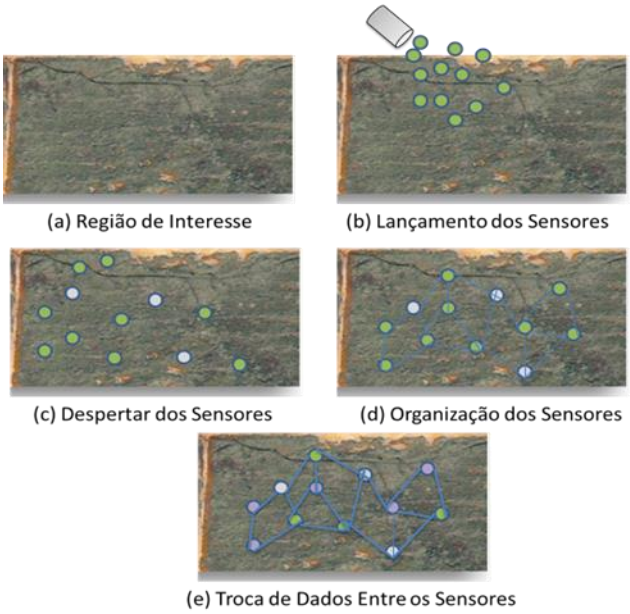

Figure 2. WSN establishment.

```
for(i=minlat; i<=maxlat; i=i+interval){
   for(j=minlong; j<=maxlong; j=j+interval){
     //verify if point (i, j) belongs to the polygon
     contains = containspoint(i, j);
     if(contains){ //if the point belongs to the polygon, store it
       arraypoints.insertpoint(i ,j);
       totpoint++; //total of points stored
     }
   }
}
```

Figure 3. Algorithm for determining possible location points.

The importance of the interval parameter is also highlighted, as the smaller its value, the greater the coverage accuracy, but consequently the greater the number of possible positioning locations and the greater the computational time. The computational complexity of this problem is given by O(nm)=(n+1)m, where n is the number of different sensors, plus 1 referring to the absence of a sensor and m is the number of possible positioning points/locations (same value of totpoints in Figure 3). This characterizes the problem as having exponential behavior as a function of the input size (NP-Hard) (Garey and Johnson, 1979), therefore, it is interesting to use heuristics to find good (approximate) solutions in low computational time.

3. GENETIC APPROACH IMPLEMENTED

In this work, a GA-based approach was proposed for configuring a WSN to cover a region. The GA proposed in this work follows the structure of the basic GA as specified in

Goldberg (1989) and basically has the following steps: representation of a solution in the structure of a chromosome, generation of an initial population, an exclusion function, a procedure for reproduction of new solutions using genetic operators (selection, crossover and mutation), a solution refinement procedure and a stop classification. Each of these steps is described below.

3.1 Representation of a Problem Solution in the Structure of a Chromosome

The genetic representation indicates how a possible solution to the problem to be solved will be (Goldberg, 1989). In the case of the problem in question, each individual in the population (chromosome or solution) is represented as follows:

- There is a vector that is the size of the number of possible sensors positioning locations (totpoints) in the area to be monitored.
- The vector index indicates a possible placement location for one of the available types of sensors. Each of the n sensor types is numbered from 1 to n.
- The content of an array position (an integer) indicates which sensor type was used at the corresponding placement location. If the position value is zero, it indicates the absence of a sensor at that location.

An example of representing a solution in the structure of a chromosome is shown in Figure 4, indicating that a type 1 sensor is allocated at location 1, at location 4 a type 2 sensor, at location 9 a type 3 sensor and the other locations do not have any sensors (value 0).

1	0	0	2	0	0	0	0	3	0
1	2	3	4	5	6	7	8	9	10

Figure 4. Representation of a problem solution as a chromosome.

3.2 Generation of the AG's Initial Population

The initial population of solutions/chromosomes must be created in order to start the process. The initial population is randomly generated, where each chromosome position (possible placement location) receives a random value drawn between 0 and n (number of sensor types).

3.3 Evaluation Function

In order for each solution to carry out the process of competition for the survival of the fittest, it is necessary that each solution has an associated value (Michalewicz, 1996). It is calculated as described below. At the position of the chromosome whose value is different from zero, the value of the corresponding sensor type is added and the next position is moved. However, in a position of the chromosome whose content is zero (absence of sensor), it must be verified if the corresponding location is being covered by a sensor that is in another location. If it is being covered, the cost of the solution does not change. Otherwise, a penalty is added to the cost of the solution (in this work it was considered ten times the highest cost of the available sensors) for having a location not covered by any sensor.

3.4 Mechanism of Selection and Reproduction of Chromosomes

The selection mechanism adopted in the proposed GA is a tournament of 3 elements (chromosomes) randomly drawn, where the best of the 3 goes on for reproduction (WIRSANSKY, 2020).

As for the reproduction mechanism, the classic 1-point method was considered in the crossover operation and in the mutation operation the change of the value of a position in the chromosome by another value drawn randomly between 0 and n (Goldberg, 1989).

3.5 AG Stop Criterion

The stopping criterion adopted was simply to reach the specified number of generations.

3.6 Refinement of the Best Chromosome (Solution)

In general, refinement of the best solution obtained by GA is used in order to obtain even better solutions (Michalewicz and Fogel, 2004). In this work, the refinement process was applied to the best solution obtained by the GA and carried out as follows: for each position whose content is different from zero (contains a sensor), the possibility of removing it without any location of possible placement is uncovered. If this occurs, the position value is changed to zero and the cost of the removed sensor is subtracted from the solution value.

4. COMPUTATIONAL EXPERIMENTS, RESULTS AND DISCUSSION

Next, the simulations and computational results performed by the execution of the GA-based heuristic proposed for the configuration of a WSN to cover a region will be presented. The technique was implemented in Java using the GoogleMaps API (Brown, 2006) for data entry and presentation of results and executed on a machine with an Intel Core I5 M450 2.4Ghz processor and 4 Gb of DDR3 RAM. The parameters used in the GA after empirical tests were: 50 for the population size, 50 for the number of generations, 80% (0.8) for the crossover probability and 2% (0.02) for the mutation probability.

The process begins with the determination of the area to be monitored, the number of types of sensors (in this case 3) and the coverage accuracy interval in Km (in this example 0.1) as can be seen in Figure 5.

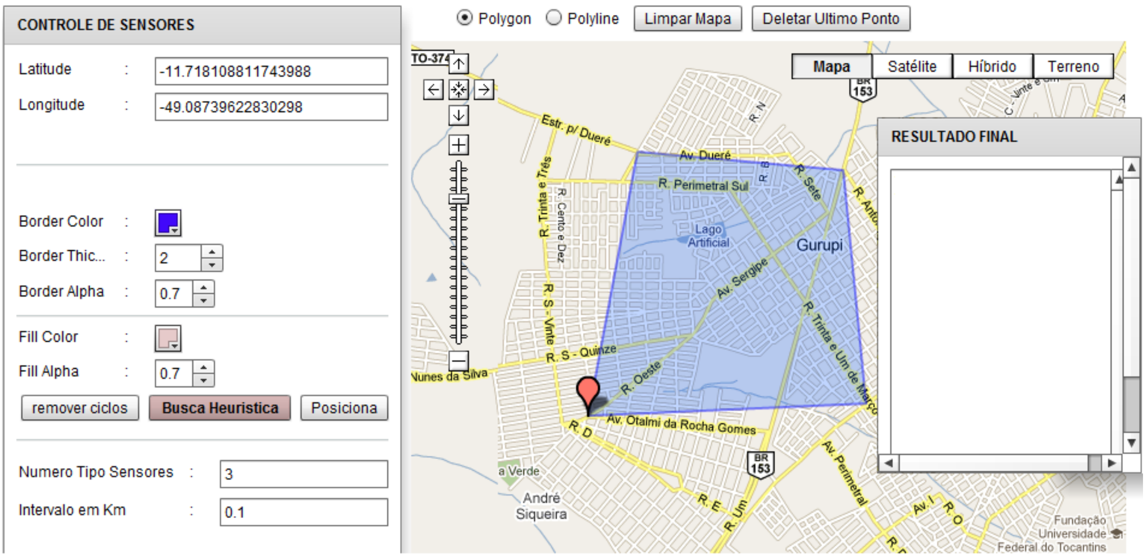

Figure 5. Interface of the system.

The next step is to click on the heuristic search button to enter the costs and radius of action in Km for each sensor and then run the proposed AG-based heuristic.

Considering the coverage accuracy interval in Kilometers (Km) as 0.1 (100m) and the number of sensors as three (3) with the respective radii of 0.1, 0.2 and 0.3 Km and cost of 1, 2 and 3, we have the solution presented in Figure 6 for the area provided in Figure 5. This solution presents 240 possible placement locations with a value of 135 before the best solution refinement process and 65 after with a running time of 12.58 wall-clock seconds.

Already considering the coverage accuracy interval in Km as 0.05 (50m) and the number of sensors as three (3) with the respective costs of 0.1, 0.2 and 0.3 Km and cost of

1, 2 and 3, we have the solution presented in Figure 7 for the area provided in Figure 5. This solution presents 953 possible placement locations with a value of 518 before the best solution refinement process and 81 after and execution time of 65.23 wall-clock seconds. It is mentioned that the red circles have a radius of 0.1 km, the blue ones 0.2 km and the green ones 0.3 km.

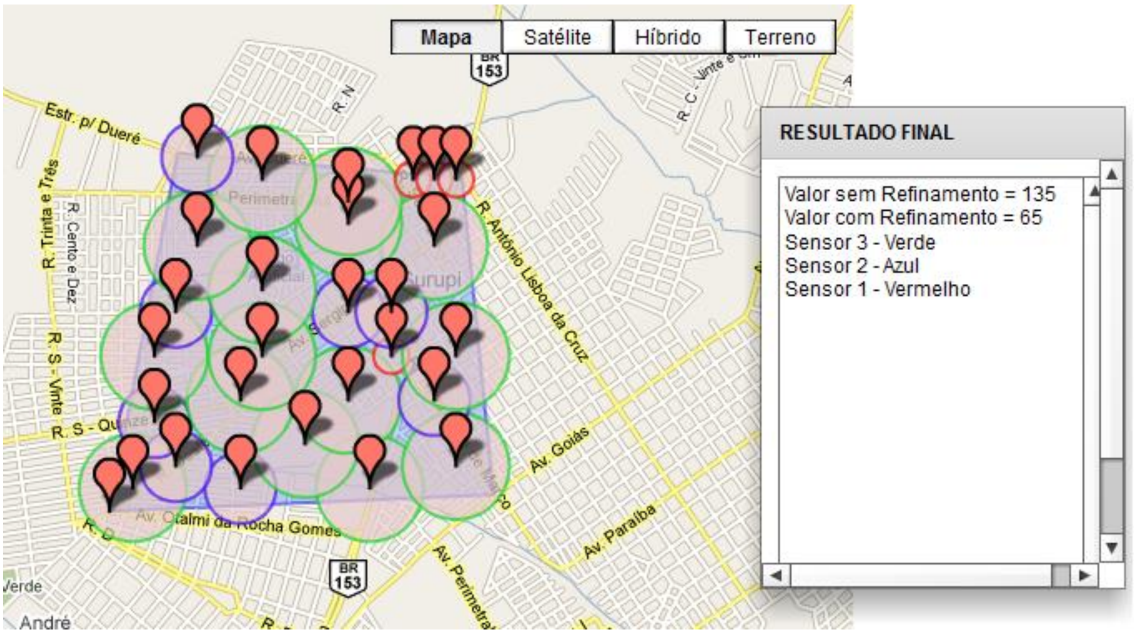

Figure 6. Possible solution with 3 sensors and 0.1 Km range.

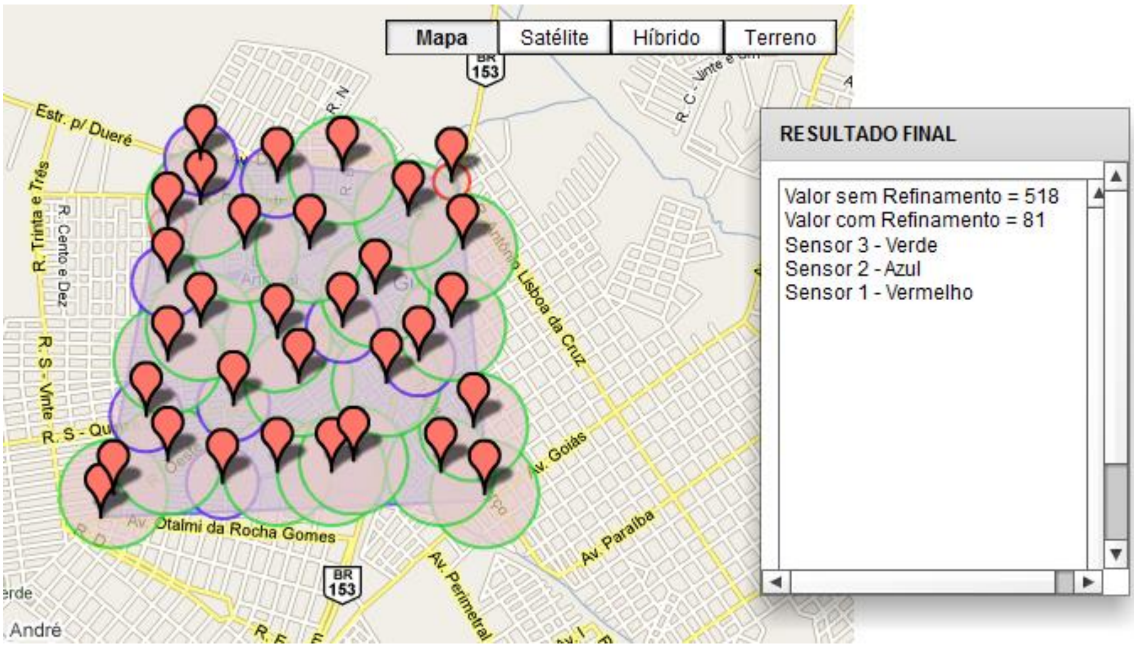

Figure 7. Possible solution with 3 sensors and 0.05 Km range.

As mentioned in Section 2 of this work, the smaller the interval, the greater the accuracy of coverage of the region and consequently the greater the number of possible positioning locations, resulting in greater computational time and an increase in the cost of the presented solution, which was confirmed by the experiments carried out. Another issue worth mentioning is the good efficiency of the refinement method, eliminating the use of unnecessary sensors to maintain coverage of all positioning locations and consequently reducing the final cost of the solution. In the tests carried out, an average of 70% of unnecessary nodes were eliminated.

5. FINAL CONSIDERATIONS

In this work, a GA-based heuristic was presented for the problem of configuring a WSN to simulate the coverage of a specified region. Computer simulations were performed using several types of sensors, where each one had a different cost and sensing radius, as well as variations in the intervals (maximum distance) between the sensors.

In the simulations carried out, it was verified that the proposed GA met the requirement of covering the specified area with the sensors and that the refinement method worked satisfactorily, providing lower cost solutions. Another relevant factor was the influence of the precision range considered, which the smaller, the higher the cost of the solution.

According to the computational results presented, good solutions were obtained in low computational time for such a complex problem (NP-Hard) and with a large number of practical applications.

In terms of future work, there are several possibilities, among them: parallelization of the GA to increase performance and consequently a greater number of simulations, use of the best most efficient solution refinement method, use of other heuristics (ILS, VNS, etc.) between others.

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