Deployment of 3D Wireless Sensors within Forest Based on Genetic Algorithm

Weiwei Cui, Liang Zeng, Qi Li, Yang Zhang, and Jing Liang

University of Electronic Science and Technology of China

Abstract. This paper introduces a non-uniform wireless sensor network (WSN) deployment strategy based on genetic algorithms in forest environment. A new fitness function is proposed which emphasizes on WSN's convergence and connectivity. According to the fitness function, The deployment strategy selects the best topology in mounts of random network development samples. Then, Minimum spanning tree is employed to optimize connectivity and fix the WSN's partially damaged problem. Simulation shows that the deployment strategy suits for forests with complex terrain and communication obstacles.

Keywords: deployment strategy, wireless sensors, genetic algorithm, minimum spanning tree

1 Introduction

The protection of forest resources is an important issue which is widely focused. How to effectively monitor the entire forest area, in order to prevent fire, reduce theft and other issues, have been under study. Now, WSNs have made a huge breakthrough in the problem. The deployment strategy in forest environment becomes a research focus.

At present, the strategy of the two-dimensional wireless sensors deployment has been well studied. Representative researches on mobile WSN of two-dimensional plane mainly include diffusion method of node moving based on the potential field [1], the three protocols, VEC, VOR and Mini-max based on Voronoi diagram [2], and the improved virtual force algorithm of co-evolution particle swarm (VFCPSO) [3]. These methods are based on the virtual force, assuming that the monitoring area is evenly distributed.

And the three-dimensional situation is still under study. When one more dimension is added, whether the conclusion of the two-dimensional case can be applied in three dimensions or not, needs to be verified.

The frontier works for the deployment of WSN in three-dimensional spaces include the polynomial time algorithm [4], EXCHANGEID and ASSIGNCODE agreement [5]and Vorinoi polygon graph of nodes deployment strategy [5]. But [4] and [5] assume that monitoring events in three-dimensional spaces are evenly distributed. [6] can guarantee 100% spatial coverage and minimum node count, and also apply to the section on the condition of the stationary and moving, but it only assumes that the monitoring scope of all nodes is the same.

At present, there are some researches of the deployment of WSN based on genetic algorithm [7], but mostly based on the 2-D plane, or only consider the problem of coverage in three-dimensional spaces. This paper puts forward an algorithm that can solve deployment problem of WSN in the forest, which can realize both nice coverage (90%) and full connectivity, and can be also applied to heterogeneous sensors, different terrain, and it is easy to deal with problems of obstacles and repairing network damages.

Specifically, the main structure of this development strategy is the iteration of genetic algorithm. The genetic algorithm includes three parts – sorting order, crossover and mutation. The optimal development solution that satisfies metrics of coverage (90%) and full connectivity can be found after several times iterations. Minimum spanning tree plays three roles: finding the number of additional sensors for fitness function, optimizing connectivity and fixing WSNs with partially damaged problems. According to solutions for actual geographical conditions, locations of sensors can be constrained by terrain and obstacles of forest areas.

The rest parts are organized as follows: Section 2 introduces some measurement parameters and gives a fitness function which is used to assess the performances of one WSN. In section 3, the detailed steps of this deployment strategy are displayed. Section 4 shows some simulation results using MATLAB .Conclusion and future work are mentioned in section 5.

2 Measurement of Network Performance

The main metric for measuring the performances of WSN is the fitness function function with coverage and connectivity.

2.1 Coverage

Assuming that one area of the forest is a cube of V (a*a*a), the number of sensors in the cube is N, and the determination of the N values here is related to the density of the trees in the forest. More sensors can be deployed in dense forests, while sparse forests deploy fewer sensors. In this study, we take a wireless sensor as a Boolean model, which is a sphere with a detection radius of Rs. A single wireless sensor can cover a range:

$$v_i = \frac{4}{3}\pi Rs^3 \tag{1}$$

Define the coverage scope for all sensors of a WSN:

$$V_{\text{cover}} = \bigcup_i v_i \tag{2}$$

Assume the total space is V, and define the coverage of a WSN:

$$f_1 = \frac{v_{\text{cover}}}{V} \tag{3}$$

2.2 Connectivity

Assume that the communication radius of the sensor is R_c, which one sensor can be connected to other sensors if the distances between 2 sensors is less than or equal to R_c. To ensure that network is fully connected, we calculate the minimal number of additional sensors that can make the whole network connected, and introduce Δi to measure the connectivity of the WSN. The concrete calculation of Δi: find the minimum spanning tree of the existing network deployment scheme and paths that are longer than the communication radius. The number of additional nodes on the path L_j where [] representing to be rounded down.

$$\Delta ij = \left[\frac{L_j}{Rc} \right] \tag{4}$$

The minimum number of additional sensors to make the whole network connected:

$$\Delta i = \sum\nolimits_j \Delta ij \tag{5}$$

2.3 Fitness Function

$$f = \frac{5}{8} f_1 + \frac{3}{8} \frac{\Delta i}{\left(\frac{a}{Rs} + 1\right)^3 - N} \tag{6}$$

(6) is called fitness function and includes the information of coverage and connectivity, where f_1 is the coverage of one certain WSN. a is the length of a small area. $N$is the number of sensors in the WSN.

3 Deployment Strategy of Wireless Sensor Networks

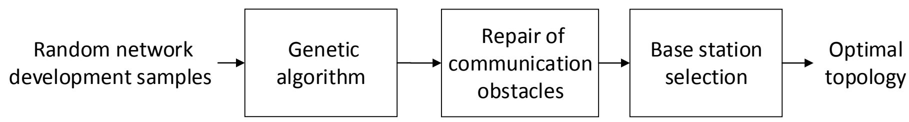


Fig. 1: The deployment strategy

Under the assumptions of sufficient energy and isomorphic sensors, the deployment strategy includes the genetic algorithm, minimum spanning tree and traversal to achieve improving coverage (90%) and full connectivity.

3.1 WSN's selection based on Genetic Algorithm

The following discussion is to solve the deployment problem of WSNs in a forest with the forest trees in uniform distribution. The forest area is broad. Therefore, we divide the forest area into some small parts. We just consider the WSN in a small area. Then link every small part with base stations. We use the genetic algorithm to solve the development of WSN with N wireless sensors in one small part of forest area.

Initialization: We get M (M is odd) network deployment samples with N sensors randomly placed in a small part of forest area. Note that we limit that the sensors are only set over the ground.

Sorting order: We use the fitness function to assess the performance of each sample. Then, sort these samples from good to bad. We ensure the first order of these samples is always the best one.

Crossover: Except for an optimal sample, the remaining $M-1$ samples were paired off randomly as parents. Each parent is randomly selected and marked half of the sensors. A pair of parents exchange marked positions with each other. After that, we get $M-1$ new samples.

Mutation: In order to speed up the process of getting the ideal solution, we make mutations for $M-1$ new samples that we get from crossovers. The concrete method is as follows: for each network deployment sample, we move the most wasteful node to the most open place.

Loop: After we get M new samples, we repeat the steps from sorting order to variation until the repeat count reaches to the number we give. End: When the loop is broken out, we do one more sorting order step. The first sample is the one we need.

3.2 Repair of the Best Sample with Minimum spanning tree

Even if we get a relatively optimized sample, that is, coverage approximate 90%, connectivity is also better, we cannot ensure that the WSN achieves full connectivity. In order to get a fully connected network, we need to repair the best sample we get from genetic algorithm. The main practice is to find the minimum spanning tree of the existing nodes and mark path L_k that is longer than the communication radius R_c.Like (4) and (5), the number of new sensors for repairing:

$$\Delta ik = \sum\nolimits_k \left[\frac{L_k}{Rc}\right] \tag{7}$$

Since we mark a set of path L_k and the locations of their sensors on endpoints, these new sensors for repairing the WSN need to be put on the path L_k evenly.

This step also adapts to the situation that there is the breakdown between two connected sensors, which cause the whole network disconnected. We can use the same method to add new sensors, so that the network can connect again. This makes our deployment strategy more flexible.

3.3 Determining the Best Position of a Base Station for One Cube Area

After determining the distribution of the sensors within an area, we need to find the location of the base station. The theoretical analysis shows that the utilization of energy in the WSN decreases rapidly when the hops of the sink node increase. The location of sink node is where we need to place the base station. To improve the utilization of the sensor network and extend the service life of the network, we need to find a location of sink node, which makes the maximum hops of the network as small as possible.

The idea of realization: we use KRUSKAL algorithm to find the minimum spanning tree of WSN and mark leaf nodes of the minimum spanning tree. Next, find the minimum spanning tree root nodes set from leaf nodes to the inside. Finally, we determine the location of the base station that is closest to all root nodes.

4 Simulations

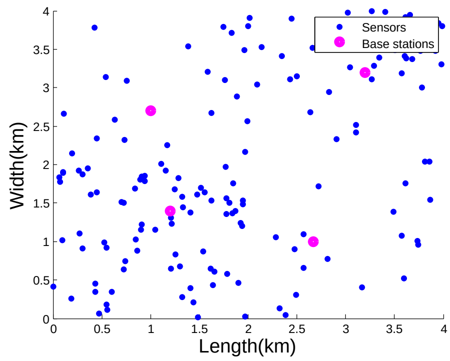
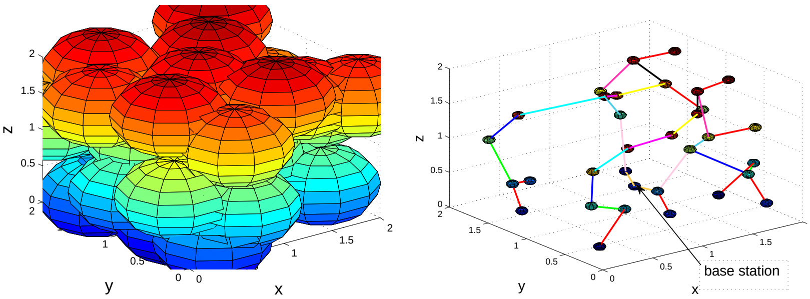


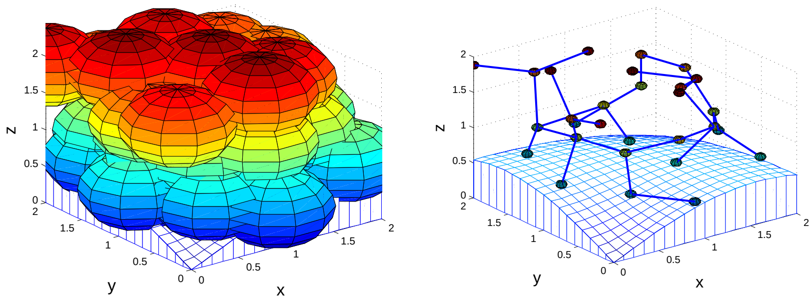
Fig. 2: Sketch map of sensors and base stations

Fig.2 shows an overhead view of WSN in the forest. From Fig.3, we get a deployment of WSN whose coverage rate is 87.71% and can be fully connected. This result basically meets our requirements. And from Fig.4, after we take terrain into account, we get a result whose coverage rate is 91.62% and can be fully connected. From the two cases, we can conclude that this algorithm fits both situations well, and can get a satisfying result. When the WSN breaks down, some sensors that could be connected cant be connected with each other now. We propose a method to solve this problem. As Fig.5a shows, the blue line means the connected path is a breakdown. After our repair plan, we add an extra sensor to make the WSN fully connected again, just as Fig.5b shows. This case



(a) (b)

Fig. 3: WSN's performance in flat terrain (a) The coverage of WSN. (b)The connectivity of WSN.



(a) (b)

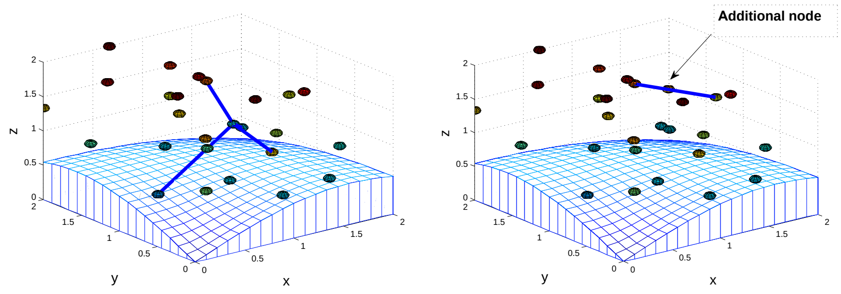
Fig. 4: WSN's performance in complex terrain (a) The coverage of WSN. (b)The connectivity of WSN.

indicates that our deployment strategy is easy to repair, which can also extend our network life.

We change some parameters to detect the performance of our deployment strategy. First, we change the communication radius R_c and the detection radius R_s. As Fig.6 shows, when $R_c/R_s = 1.7$, both coverage and connectivity achieve the best. Second, we change the number of variation sensors per iteration. From Fig.7, we can conclude that varying one sensor per iteration is the best.

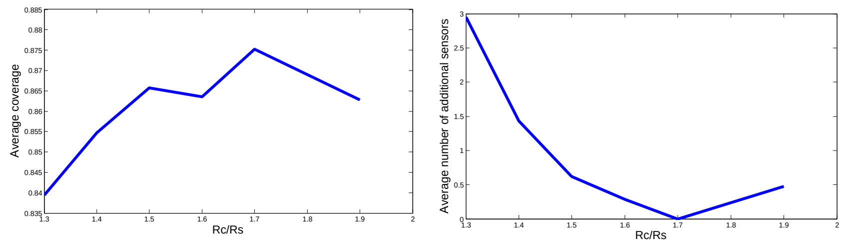
5 Conclusion

This paper introduces genetic algorithm to solve WSN's deployment problem. Combining with actual problems in the forest, it comes up with a deployment



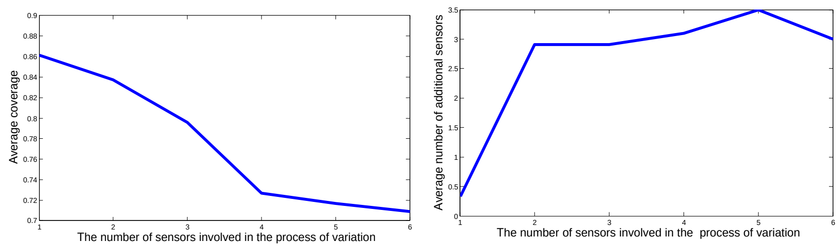
(a) (b)

Fig. 5: The restoration of WSN (a) before repaired. (b) After repaired.



(a) (b)

Fig. 6: The influence of R_c/R_s to the WSN's performance (a)The influence on coverage. (b)The influence on connectivity.



(a) (b)

Fig. 7: The influence of mutation sensors to the WSN's performance (a)The influence on coverage. (b)The influence on connectivity.

strategy that can realize remarkable coverage and connectivity at the same time. This deployment strategy is flexible and can be easily modified and repaired with minimum spanning tree. Simulations show the coverage rate is 87.71% in flat terrain and it can reach 91.62% even considering complex terrain.

In the future, we are going to consider energy loss and heterogeneous sensors so that this algorithm can have a wider scope of application in forest protection.

Acknowledgments

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