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Rearrangement of mobile wireless sensor nodes for coverage maximization based on immune node deployment algorithm ☆

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ABSTRACT

One of the primary objectives of Wireless Sensor Network (WSN) is to provide full coverage of a sensing field as long as possible. The deployment strategy of sensor nodes in the sensor field is the most critical factor related to the network coverage. However, the traditional deployment methods can cause coverage holes in the sensing field. Therefore, this paper proposes a new deployment method based on Multi-objective Immune Algorithm (MIA) and binary sensing model to alleviate these coverage holes. MIA is adopted here to maximize the coverage area of WSN by rearranging the mobile sensors based on limiting their mobility within their communication range to preserve the connectivity among them. The performance of the proposed algorithm is compared with the previous algorithms using Matlab simulation for different network environments with and without obstacles. Simulation results show that the proposed algorithm improves the coverage area and the mobility cost of WSN.

1. Introduction

A Wireless Sensor Network (WSN) is a distributed system which is composed of tiny, low-cost, battery-operated sensor nodes that collaborate together for the purpose of achieving a certain task. For instance, WSNs can be used for environment and habitat monitoring, traffic measurement on roads, vehicle tracking and personnel tracking inside buildings [1]. Coverage is one of the most important performance metrics for Wireless Sensor Networks (WSNs) since it reflects how well a sensor field is monitored. The coverage problem in WSN has been addressed either as a target coverage or an area coverage [2]. The target coverage algorithms are adopted to maximize the number of targets that could be covered based on assumption that the sensing field is divided into targets [3,4]. On the other hand, the area coverage algorithms are used to maximize the covered area of the whole sensing field [5–11].

The deployment strategy of sensor nodes in the sensor field is the most critical factor related to the network coverage. The sensor nodes can be deployed either deterministic or random. A deterministic deployment may be feasible in friendly and accessible environments. While, a random deployment is usually preferred in large scale WSNs not only because it is easy and less expensive, but also it might be the only choice in hostile environments such as battle field or forest environment.

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However, random deployment of the sensor nodes can cause coverage holes in the sensor field; therefore, in most cases, random deployment is not guaranteed to be efficient for achieving the maximum coverage [4–7].

Solution of the coverage holes' problem depends on how the sensor nodes are rearranged with respect to each other to maximize the coverage area and also prolongs the operational life of the individual nodes with limiting the mobility cost. This is Non-deterministic Polynomial-time hard (NP-hard) problem [12,13]. Therefore, a new deployment algorithm based on Multi-objective Immune Algorithm (MIA) [14–16] and binary sensing model is proposed here to solve the above mentioned problem. The proposed algorithm utilizes the MIA to rearrange the random deployed sensor nodes based on maximizing the coverage area and minimizing the dissipated energy during the movement process. Moreover, the proposed deployment algorithm preserves the connectivity among the sensors by limiting their mobility within their communication range. The paper is organized as follows. Section 2 is a literature survey about various deployment algorithms. The network and sensing models and the objectives of the proposed algorithm are described in Section 3. Section 4 explains the proposed immune node deployment algorithm and how the multi-objective immune algorithm is used to maximize the covered area and minimizes the consumed energy during the movement process. In Section 5, the simulation results and discussion are given. Finally, Section 6 offers some conclusions.

2. Related work

Many deployment algorithms have been developed in literature [1] and [3–11] to solve the problem of coverage holes. The developed deployment algorithms are based on introducing the mobility to some sensor nodes or to all sensor nodes in the sensor field in order to improve the coverage of WSN. In [1], authors used a genetic algorithm with introducing the mobility to all sensor nodes in the network in order to provide the trade-off between coverage and nodes' traveled distance. A real-time genetic algorithm was developed in [3] to find the suitable direction of node locomotion, considering either coverage of the target area or estimation of the optimum energy consumption. While in [4], authors exploited the genetic algorithm to maximize the network coverage and to alleviate the coverage holes by finding the minimum number of additional mobile nodes and their best positions in the sensing field. Particle Swarm Optimization (PSO)-based deployment approach was presented in [5] to maximize the network coverage rate based on finding positions of the mobile sensor nodes. Nevertheless, the cost of mobility is not considered here.

Authors in [6] introduced limited mobility based coverage algorithm for the multi-hop WSNs by identifying the redundant sensing regions during the post deployed scenarios and maintain the network with limited mobility. Decision of mobility of the nodes among immediate neighbors of a dead node is totally autonomous and distributed, and it is made to maintain the network without disturbing the existing coverage and connectivity. A number of distributed algorithms for the deployment of mobile nodes were adopted in [7] to improve an irregular initial deployment of nodes and maximizes the network coverage. The first one is Distributed Self-Spreading Algorithm (DSSA). DSSA is used to improve the network lifetime and the coverage rate by introducing the mobility to all sensor nodes. The Intelligent Deployment and Clustering Algorithm (IDCA) is the second algorithm adopted for clustering WSN based on peer-to-peer mode. In peer-to-peer algorithm, each node moves itself to coverage holes to increase the network coverage rate and to prolong the network lifetime. Finally, the third algorithm introduced in [7] is a Voronoi Diagrams-based Deployment Algorithm (VDDA). This algorithm uses a distributed fashion in which each node determines how long it can survive and which action is more useful to prolong the network lifetime during deployment.

In [8], a two-phase Wireless Sensor Network Particle Swarm Optimization (WSNPSO) algorithm was presented to enhance the network coverage and the moving energy consumption. The objectives of this algorithm are achieved in separate phases with coverage maximization in the first phase while energy conservation in the second phase. An optimization scheme based on a multi-objective evolution algorithm is adopted in [9] to adjust the positions and the sensing radius of the sensor nodes to increase the network coverage rate and to reduce the sensing energy consumption and the redundant coverage. A coverage optimization strategy based on the evolution of Multi-particle Particle Swarm Optimization (MPSO) has been developed in [10] to improve the network performance and the network coverage rate. MPSO depends on adopting a number of particles independently searching for solutions' space to improve stability of the algorithm.

In [11] Biogeography-Based Optimization (BBO) algorithm has been adopted to improve the WSN coverage after initial deployment of the sensors. However, this algorithm has slow convergence. So, a Virtual Force (VF) algorithm is incorporated to improve the convergence speed of BBO algorithm. Moreover, VF-BBO algorithm outperforms BBO algorithm in the coverage area.

3. Network and sensing models and objectives of the proposed algorithm

In this section, we state some assumptions about the sensor network model. Furthermore, the binary sensing model and the objectives of the proposed algorithm will be discussed.

3.1. Network model

To develop the proposed algorithm, the following assumptions about the sensor nodes are fixed: