Ad Hoc Networks 46 (2016) 12–22

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Dynamic deployment of randomly deployed mobile sensor nodes in the presence of obstacles

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ARTICLE INFO

Article history:
Received 3 November 2015
Revised 20 February 2016
Accepted 7 March 2016
Available online 31 March 2016

Keywords:
Coverage
Connectivity
Mobile sensor network
Node deployment
Virtual force

ABSTRACT

For random deployment of wireless sensor networks in a specified geographical location and in the presence of obstacles, optimal network coverage is highly desirable while maintaining network connectivity. In this piece of work, we propose an efficient autonomous deployment scheme, named as Obstacle Avoidance Virtual Force Algorithm (OAVFA), for self-deployment of randomly scattered homogeneous as wells as heterogeneous mobile sensor nodes over a squared sensing field to enhance the network coverage and ensure the network connectivity in the presence of obstacles. Our proposed approach is localized in the sense that each decision taken by the sensor node is strictly based on information acquired from its neighbors. The simulation results show that OAVFA provides an efficient self-deployment of mobile sensor nodes in the presence of obstacles.

1. Introduction

Nowadays, Wireless Sensor Networks (WSNs) have attracted tremendous research interest due to its various applications from environment monitoring, battlefield surveillance, target tracking, wildfire detection, precision agriculture, smart homes and offices, industrial process monitoring and asset management [1]. A mobile sensor network is a collection of inexpensive, low-powered, small size, and multifunctional mobile sensor nodes. The effectiveness of WSNs mainly depends on the network coverage, lifetime and connectivity provided by the sensor deployment strategies such as deterministic and random deployment. Placing sensor nodes manually in predetermined positions on the basis of simple geometric structure (e.g., Hexagon, Square, Rhombus, and Triangular Lattice) is simple and optimal, but this deployment strategy is not suitable in many applications where the application environment is unknown, hostile or inhospitable. For these applications, sensor nodes are required to be deployed randomly by means of dispersing sensors from aircraft or artillery ordinance.

An efficient self-deployment algorithm is highly required to ensure optimal network coverage while maintaining connectivity for such randomly deployed sensors. Presently, virtual force-based self-deployment strategies are adopted to overcome the limitations exhibited by random deployment [2–10]. In this work, an efficient distributed self-deployment algorithm has been proposed for randomly deployed homogeneous as well as heterogeneous mobile sensor nodes. This algorithm is named as Obstacle Avoidance Virtual Force Algorithm (OAVFA). Experimental results carried out with our proposed algorithm not only maximizes coverage area but also ensures the connectivity between all sensor nodes in the presence of obstacles. A set of sensor nodes with identical speeds, communication ranges, and sensing ranges has been identified as homogeneous sensor nodes while heterogeneous sensor nodes differs only in the sensing ranges which are strictly different for various sensors. It has been assumed that the speeds and the communication ranges for heterogeneous sensor remain constant during the process.

The proposed algorithm is localized and executed at each sensor node. In this algorithm, each sensor node considers all attractive and repulsive virtual forces due to its neighboring sensor nodes, obstacles, and the sensing field boundary to determine its movements to enhance the network coverage while maintaining connectivity, prevent the sensor nodes from moving out of sensing field boundary, and avoid the obstacles. Here neighbor sensor nodes of *i*th sensor s_i means the sensor nodes that are within the communication range of s_i.

In the next section, a brief but latest literature surveys on sensor node deployment has been outlined. Section 3 provides a basic discussion about the network coverage and sensing model. Our proposed deployment algorithm, Obstacle Avoidance Virtual Force Algorithm (OAVFA) has been de-

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http://dx.doi.org/10.1016/j.adhoc.2016.03.004
1570-8705/

scribed in Section 4. In Section 5, simulation results are presented followed by conclusions in Section 6.

2. Related work

Sensor arrangement is an imperative issue for some essential objectives in WSNs like coverage, lifetime, and connectivity. For randomly deployed sensor networks, an efficient deployment algorithm is required to self-deploy the mobile sensor nodes to maximize coverage area, ensure the network connectivity and prolong the network lifetime. In [2,3], an incremental and greedy algorithm is presented in which nodes are deployed one at a time. The objective is to maximize the coverage under the constraint that nodes maintain line of sight with each other. Howard et al. [4] have presented a centralized deployment approach based on potential field theory to deploy the mobile sensor nodes (mobile robots) in an unknown environment to enhance the network coverage. In [5,6], the sensor nodes are placed in a grid-like manner to ensure coverage and connectivity. A robust and scalable deployment scheme, based on simulated annealing technique for complete coverage is presented in [7]. In [8], Heo and Varshney have proposed a distributed self-deployment algorithm for mobile sensor networks to maximize the coverage and to maintain uniformity in node distribution. Poduri and Sukhatme [9] have proposed a deployment scheme for mobile sensor network to enhance the network coverage with maintaining K-connectivity. In [10], Guo et al. have proposed an adaptive coverage algorithm by considering inner repulsion, random disturbance and boundary contraction to maximize the coverage. By combining the potential field theory and the plate coverage theory, a centralized deployment algorithm called as a Virtual Force Algorithm (VFA) is presented in [11,12]. This VFA cannot quickly converge to a steady state. In [13], the authors proposed a sensor deployment optimization strategy based on Target Involved Virtual Force Algorithm (TIVFA) to improve coverage and detection probability. In [14], Wang et al. have proposed several algorithms that identify existing coverage holes in the network and compute the desired target locations where sensor should move in order to increase the coverage. In [15], the authors developed a decentralized and scalable algorithm based on potential field theory for motion control of mobile sensor networks to cover the maximum area of the free space in minimum time. A localized algorithm for determining whether every point in the service area of the sensor network is covered by at least k sensors is presented in [16]. Voronoidiagram and Delaunay triangulation are used in [17] to estimate the worst and best case coverage in a sensor network. In [18], the authors used Delaunay triangulation, Gabriel graph and relative neighborhood graph to find the path with best coverage. A few excellent surveys on the present state-of-the-art research on sensor network is presented in [19–23]. In [24], the authors have explored> geographic routing in duty-cycled mobile WSNs and proposed two geographic-distance-based connected-k neighborhood (GCKN) sleep scheduling algorithms for geographic routing schemes. In [25], the authors gave necessary and sufficient conditions for 1-coverage and 1-connected wireless sensor grid network. Tian and Georgansa [26] have proved that the communication range is twice of the sensing range is the sufficient condition for complete coverage preservation implies connectivity among active nodes if the original network is connected. The optimal deployment patterns to achieve both full coverage and connectivity for all ranges of Rc/Rs is presented in [27–29]. In [30], the authors proposed a self-deployment mechanism that allows to maintain network connectivity during the deployment of mobile sensor nodes. This mechanism is robust against message losses during deployment. Shen et al. [31] have proposed a grid scan method to calculate coverage rate for arbitrary sensing radius. The main objective of this approach is to provide a better coverage with less nodes. In [32], the authors developed a mechanism to replace failed sensors in a large-scale static sensor networks by using few mobile robots. The goal of this work is to minimize the motion and the messaging overhead. Chen et al. [33] have proposed two novel algorithms named as Improved Virtual Force Algorithm (IVFA) and Exponential Virtual Force Algorithm (EVFA) to improve the performance of traditional VFA. In [34], the authors presented an efficient deployment algorithm named as Self-Deployment by Density Control (SDDC). In this work, virtual force is decided by density at a sensor node and obstacles and the algorithm is not suitable for sparse initial distribution. In [35], Kribi et al. have proposed Dth_Lmax_Serialized_VFA algorithm to enhance coverage and maintain network connectivity of the sensor networks. A Virtual Force directed Co-evolutionary Particle Swarm Optimization (VFCPSO) is presented in [36]. This algorithm is appropriate for small scale application due to its high computation time. Yu et al. [37] have proposed an algorithm base on virtual force and the concept of adjacent relationship of nodes to enhance the coverage rate and reduce the convergence time. A Distributed Virtual Forces Algorithm (DVFA) is proposed in [38] to establish coverage and connectivity. The problem of connectivity optimization in random 3D networks is addressed in [39] where the deployment problem considers the maximization of network connectivity satisfying lifetime constraints. Autonomous mobile robots that deploy a wireless sensor network to be used in disasters is introduced in [40]. In [41], the authors proposed a deployment algorithm for heterogeneous sensor networks based on the circle packing technique to enhance the coverage area. In [42], Xiaoping et al. have analyzed the performance of different virtual force models used in node deployment algorithms.

In this work, an obstacle avoidance VFA is introduced for deployment of both heterogeneous as well as homogeneous mobile sensor nodes over a squared sensing field containing different shape of obstacles.

3. Coverage and sensing model

Coverage is one of the key parameters to evaluate the performance of deployment algorithms [2–9]. According to Poduri and Sukhatme [9], there are three categories of coverage: barrier coverage, target or point coverage, and area coverage. In barrier coverage, sensor nodes have to form a barrier to detect intruders. Target coverage refers to monitoring fixed number of targets in a Region of Interest (ROI). Area coverage means that every point within ROI must be monitored by at least one sensor node or by the joint detection of several sensor nodes. Usually, this coverage is necessary when applications need to monitor the entire area of interest. In general, area coverage [31] means how well the ROI is monitored by the sensor network and is evaluated as in (1).

$$\text{Coverage}(C) = \frac{\cup_{i=1,\ 2,\ \ldots,\ N} A_{si}}{A_{Tot}} \tag{1}$$

Where A_{si} denotes the area covered by the mobile sensor node s_i, N is the number of mobile sensor nodes deployed in ROI and A_{Tot} is the area of the entire ROI.

Sensor models have direct impact on network coverage of WSNs [43]. Sensing models as reported in various literatures can broadly be classified as Binary sensor model and Probabilistic sensing model [10–13,43]. For the purpose of evaluation of our proposed algorithm, we prefer binary sensor model.

3.1. Binary sensor model (BSM)

In most of the existing work, the disk sensing model is used for coverage calculation for its simplicity. According to this model