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Coverage and Connectivity Problem in Sensor Networks

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***Abstract*—**In over deployed sensor networks, one approach to Conserve energy is to keep only a small subset of sensors active at Any instant. For the coverage problems, the monitoring area in a set of points that require sensing, called demand points, and consider that the node coverage area is a circle of range R, where R is the sensing range, If the Distance between a demand point and a sensor node is less than R, the node is able to cover this point. We consider a wireless sensor network consisting of a set of sensors deployed randomly. A point in the monitored area is covered if it is within the sensing range of a sensor. In some applications, when the network is sufficiently dense, area coverage can be approximated by guaranteeing point coverage. In this case, all the points of wireless devices could be used to represent the whole area, and the working sensors are supposed to cover all the sensors. We also introduce Hybrid Algorithm and challenges related to coverage in sensor networks.

***Keywords*—**Wireless sensor networks, network coverage, Energy conservation, Hybrid Algorithms.

I. Introduction

WIRELESS sensor networks are often deployed for passive data-gathering or monitoring in a geographical region. An important issue here is to maintain the fidelity of the sensed data while minimizing energy usage in the network. Energy is spent due to message transmissions among sensor nodes or due to the sensing activities by the signal processing electronics. Energy can be saved if these activities are used only to the extent absolutely needed, and no more. In this article, we address the two important characteristics, viz., coverage and connectivity of a sensor network [1]. A wireless sensor network is composed of many sensors with limited energy supply. Therefore, it is important to save energy for the sensors to extend their lifetime. One basic idea for energy saving is to separate sensors into different groups such that every group of sensors can handle the job independently. When one group is working, the other groups can be set to sleep. In a WSN, a sensor covers a target if the target is in the sensing range of the sensor. There exist three coverage models depending on how targets are defined:

1) Targets form a contiguous region and the objective is to select a subset of sensors to cover the region [14]. Typical solutions involve geometry properties based on the positions of sensor nodes.

2) Targets form a contiguous region and the objective is to select a subset of sensors to cover the rest of sensors [14]. This model assumes the network is sufficiently dense so that point coverage can approximate area coverage. Typical solutions involve constructing dominating sets or connected dominating sets [10] based on traditional graph theory.

3) Targets are discrete points and the objective is to select a subset of sensors to cover all of the targets. Typical solutions [13] use the traditional set coverage or bipartite graph models.

Our work proposes an ILP formulation and algorithms to solve the Coverage and Connectivity Control Problem (CCCP) in WSNs subject to node failures due to mechanical problems or when battery runs out of energy. We present a global algorithm which has a complete vision of the network and so can build up good topologies using the available nodes. However, spreading the solutions generated by this algorithm can be expensive in terms of energy, time and network load. Thus, we also propose a local algorithm, which is called every time a node failure occurs and solves the problem considering only the failure neighborhood. By combining both algorithms we obtain a hybrid approach which benefits from the best features of each one of them.

II. Related Work

Recently, there has been a lot of research done to address the coverage problem in sensor networks. In particular, the authors in [16] dasign a centralized heuristic to select mutually exclusive sensor covers that independently cover the network region. Megerian and Potkonjak [6] use Integer Linear Programming (ILP) to model the Coverage Problem in Wireless Sensor Networks and solve the problem by using a greedy algorithm. Vieira et al [11] use computational geometry and graph theory to solve the same problem. Nakamura et al [7] propose a mathematical ILP model to the multi-period coverage and connectivity problem in flat WSNs and solve it with the commercial optimization package CPLEX [5]. The model adds to the coverage and connectivity constraints, a set of constraints regarding the node energy limits. Quint˜ao et al [9] compare the CPLEX solutions of a multi-period ILP model that deals only with density and coverage control, to the ones obtained with an evolutionary algorithm achieving good results regarding objective function values and specially computational time. Ye et al [12] present the algorithm PEAS (Probing Environment and Adaptive Sleeping). PEAS consists of two algorithms, which determine [5] which sensor nodes should work and how a wake-up sensor node makes the decision of whether going back to sleep, and (6) how the average sleep time of the sensor nodes is dynamically adjusted to keep a relatively constant wake-up rate.

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III. Problem Definition

For modeling purposes, we discretize the monitoring area in a set of points that require sensing, called demand points, and consider that the node coverage area is a circle of range R, where R is the sensing range. If the distance between a demand point and a sensor node is less than R, the node is able to cover this point. Some of the WSNs' main limitations are energy restriction, small bandwidth, low processing and communication capacities. The energy restriction is due to the limited battery capacity and impossibility of recharge or replacement. The nodes' low cost and reduced size are main reason for small capacity of their components. The popularity of WSNs in near future depends on making them more reliable, especially in aspects such as area coverage, node connectivity and efficient resource usage. The CCCP solutions minimize the energy consumed in the network in an attempt to maximize its lifetime.

IV. Challenges We Have Faced in the Control Problem of Wireless Sensor Network Coverage

In building the wireless sensor network, network coverage is one of the fundamental issues of wireless sensor network. That is, how to deploy the sensor network nodes, under the conditions of ensuring a certain quality of service (QoS), achieve the maximization of network coverage. Measurement of network coverage will enable us to understand whether there is blind spot of monitoring and communication; understand the situation of wireless sensor network coverage in the monitor region, thus readjust distribution or guidance of sensor node when the sensor nodes can be added to the improvement measures in the future. On the other hand, it also will improve the network-related cost of transmission, management, storage and computing. Therefore, performance evaluation criteria of WSN coverage control are essential for analysis of availability and effectiveness in the coverage control strategy and algorithm.

V. Hybrid Algorithm for the CCCP

In this section, we highlight the main ideas of the two algorithms that composed our solution and describe the Hybrid Algorithm for the CCCP.

A. Global On-Demand Algorithm

The Global On-Demand Algorithm (GOD) is a hybrid approach that combines genetic and graph algorithms. See [4] for more details on this algorithm. The genetic algorithm solves the density and coverage problems, determining the set of nodes that assures the area coverage with the lowest energy consumption cost. These nodes are then connected by Minimum Spanning Tree and Shortest Path algorithms. The algorithm is on-demand because it is triggered by the hybrid approach.

B. Local Online Algorithm

The Local Online Algorithm (LOA) is used every time a failure occurs. It is called to locally restore the area coverage and the nodes connectivity choosing a node to replace the one that failed.

C. Hybrid Algorithm

The Hybrid algorithm to solve CCCP in WSNs is an attempt of combining the advantages of solving the problem in global and local ways. When the algorithm has the global vision of the network, it can find better nodes to compose the network, leading to better solutions regarding energy consumption. However this approach is not scalable and it is computationally expensive. In simulations or in real applications, the cost to disseminate the solution generated, normally using control messages is high. The local approach can be more adequate to WSNs because it is computationally cheaper, requires less control messages and is more scalable, especially when computed by the nodes. But the local vision can lead to worse solutions because the candidates to compose the network are restricted to a specific area, leading sometimes to unnecessary node activation.

The Hybrid algorithm firstly executes GOD to create an initial solution. Then, at each node failure, LOA tries to restore the coverage and connectivity. In each simulation time unit, we compare the energy consumed with the one consumed in previous time unit and if it is 5% higher it triggers the GOD algorithm to improve the configuration, given that GOD has the global vision of the network.

D. Proposed algorithm

1 Call the Global On-Demand Algorithm every 10 time units.
2 Find an initial solution.
3 Before each algorithm call, the input set S is updated.
4 The nodes that failed between the current period and the last algorithm execution are excluded from it.
5 At each node failure the Local Online Algorithm is called to try to restore the area coverage and the nodes connectivity.

VI. Future Considerations

This work proposes an ILP mathematical formulation to model the Coverage and Connectivity Control Problem in Wireless Sensor Networks subject to nodes failures and a Hybrid algorithm as an alternative to solve it. The Hybrid algorithm uses an Global On-Demand algorithm (GOD) that rebuilds all the network when required and a Local Online Algorithm (LOA) that tries to restore locally the coverage and connectivity when failures occur. We compare the hybrid approach to the optimal solution obtained by solving the ILP model, to a GOD Periodic approach that rebuilds the entire network in pre-defined time periods and to a Pure LOA approach that works locally every time a failure occurs. The combination of the global and local approaches leads to better solutions once it benefits from the advantages of both approaches, but it can be improved to reach better results when compared to the optimal solution.

VII. Conclusion

Wireless sensor networks will make the logical information world together with the real physical world, and greatly improve the awareness and ability of change world. Network coverage control is a basic problem in the implementation process of WSN. It can reflect "perceived" quality of service that is network provide. In this paper, based on the problem of WSN coverage control, we have addressed the k-(Connected) Coverage Set problems in wireless sensor networks with the objective of minimizing the total energy consumption while obtaining k coverage for reliability.

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