Coverage Problem for Sensor Networks: An Overview of Solution Strategies

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Abstract — **Coverage is one of the metrics used to quantify the quality of service (QoS) of sensor networks. In general, we use this term to measure the ability of the network to interact with – observe or react to – the phenomena taking place in the area of interest. In addition, coverage is associated with connectivity and energy consumption, both important aspects of the design process of a Wireless Sensor Network (WSN). This paper aims at offering a critical overview and presentation of the problem as well as the main strategies developed so far.**

Keywords — **Coverage, Cover Sets, Distributed Sensor Networks, Energy Efficient, Potential Fields.**

I. INTRODUCTION

SENSOR networks are networks consisted of tiny devices (motes or nodes) equipped with a set of sensors, a transceiver, a μC and memory. We use large numbers of such devices to form a network, usually deployed over a large area. Motes collaborate to perform a larger sensing task, in order to provide the user a global view of the area of interest, in which they are deployed.

Motes in most cases are running on batteries, thus energy efficiency is a major issue during design process.

Deploying redundant motes is a technique to prolong network lifetime. Deriving energy efficient way of using redundancy is a task equivalent of finding solutions to problems that are usually classified as NP-hard or NP-complete. Since motes have limited CPU power and memory, it is critical that optimal solutions to such problems are not computationally expensive. In this paper we explore the multi dimensional nature of coverage concept, and we review some of the proposed solutions in the literature, since it is hard to find comprehensive overviews of the subject, probably due to the fact that sensor networks have only recently emerged as an important research issue.

II. ENVIRONMENT AND EVENTS

Motes collaborate to perform a global sensing task, and to be able to propagate information as response to user query. Monitored events may be classified according time and space in two main aspects:

*Spatial Distribution (Localized/Distributed) :*The events of interest may be spatially localized. Wildlife tracking, vehicle tracking, perimeter breach, are considered as such. They are usually detected by a small number of sensors [1] in whose sensing range the events are taking place. The only concern is to locate the current position of the target and plot the movement path. In case of a forest fire, a chemical or biological contamination, the spatial distribution of the phenomenon is required.

Temporal Distribution (Discrete / Continuous): Measuring temperature over a large area, is a procedure that can be scheduled at regular intervals (e.g. every 2 hours) during a day. On the other hand, monitoring industrial machinery, patients in the ER, or seismic data, requires the network performing such tasks to be actively sensing at all times [2].

III. COVERAGE CONCEPT

Sensing Models:

A. Boolean or 0/1 Model: We may use a circle as an abstraction of the mote. The mote's location is the centre of the circle and the area of the circle is its sensing radius. The mote provides full coverage within its sensing radius and none outside it.

B. Continuous Model: [3] Taking in consideration that sensing ability diminishes as distance increases and that sensing devices have different hardware features, a more realistic way is to express sensing model S at any point p in the field at a distance d(s,p) from the mote s is the following:

$$S(s,p) = \frac{\lambda}{[d(s,p)]^K}$$

where λ and *K* are hardware dependent parameters.

Node Deployment Strategies:

A. Deterministic / Manual Placement: We deploy

Correponding author is Prof. Dimitrios A. Karras, Chalkis Institute of Technology, Greece, Automation Dept., Psachna, Evoia, Hellas (Greece) P.C. 34400, dakarras@ieee.org , dakarras@teihal.gr, dakarras@usa.net, fax: +30 210 9945 231, +30 22280 99625, tel. +30 6979688870 motes over a field uniformly, according to a predefined shape. An example of a uniform deterministic coverage is a grid based sensor deployment where motes are located on the intersection points of a grid (cellular). This requires manual placement, which is realistic for small number of nodes, and an accessible environment. This placement ensures complete coverage of the field with the minimum number of motes. The number of motes needed to cover a, area A is given by[4]:

$$n = \frac{2A}{\sqrt{27}\, r^2}$$

Where r is the sensing radius, n the required number of nodes, an A the area covered.

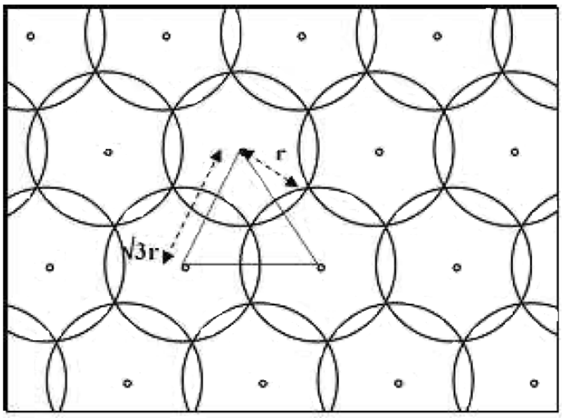

Fig.1: Optimal Placement of Motes

B. Stochastic Placement: In hostile or inhospitable environments, it's a necessity to deploy motes from a plane, in order to gather data of interest. In this case, motes are deployed randomly, and since they are of low cost, we deploy redundant motes to increase connectivity, coverage and to prolong network lifetime. In this way, some regions may be densely populated or may exhibit blind holes, areas out of any mote's sensing range. In densely populated regions, keeping all motes active causes many packet collisions thus wasting energy. In the next section we discuss coverage schemes that take advantage of the redundancy of motes in energy efficient way.

IV. COVERAGE PROTOCOLS

In a dense network, a target is covered by more than one mote. The grade of this depends on the sensing range and density of the network. It is also possible that one mote covers more than one target. The goal is to keep active only the necessary motes to cover an area. Taking it a step further, we could schedule sets of motes, all covering the same area, to be active in turns, saving energy while keeping coverage of the area.

Area Coverage

Slijepcevic and Potkonjak [6] allocate nodes into covers, mutually exclusive sets of motes. The first step is to identify the parts of the area covered by different sensor nodes.

DEFINITION: A field is a set of points. Two points belong to the same field iff they are covered by the same set of sensors.

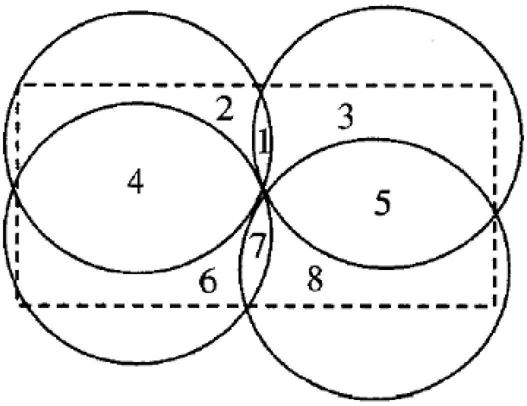

Fig 2: Four sensors covering the area (dotted rectangle) creating eight fields

The area is modelled as a collection of fields defined above. Any field has the property that any point inside the field is covered by the same set of sensors.

"The most constrained least constraining algorithm computes the disjoint covers successively, selecting sensors that cover the critical element (field covered by a minimal number of sensors), giving priority to sensors that: cover a high number of uncovered fields, cover sparsely covered fields and do not cover fields redundantly"[5].

"The downside to the scheme is that it estimates at most m covers where m is the number of sensors covering the most constrained field in the whole area. This implies that many nodes in the denser regions are not included in any cover and are left idle."[2]

Point Coverage

The maximum disjoint set covers and the maximum lifetime are two different problems [7]. In this MSc, Li Yin proposes an algorithm that finds the schedule that produces the maximum lifetime, instead of trying to find the maximum number of mutually exclusive sets.

Problem Definition: Given a set S of N motes, and a set T of M targets, find a schedule to activate motes that guarantees that at any time, all targets can be covered by active motes, and that maximizes the network lifetime.

The optimal solution is derived using a two phase algorithm. In phase one, the complete set of non redundant covers is computed. Each cover set is a subset of motes belonging to S and completely covers all targets in set T without redundant motes. In phase two, optimal solution is derived by solving the linear program – assigning the time slice for selected set covers, a schedule for sensors to e active or idle in order to achieve maximum lifetime.

Metrics for QoS of Sensor Coverage.
Two metrics are proposed [9] p. 69 concerning coverage.

A. "% of uncovered area in the region. This metric is defined as the percentage of area overthe entire region not covered by any sensor at a given time. When plotted against time, it gives an assessment of how long the network is able to achieve acceptable levels of coverage."

B. "Time at which the first breach occurs. An obvious quality measure is how long the integrity of the perimeter being sensed is maintained. When enough nodes have died so as to enable an entity to cross the perimeter without detection, a breach occurs and the sensor network effectively fails."

V. MOBILE MOTES

Potential Fields

Potential field techniques were first described by [8] and used for robotic applications such as local navigation and obstacle avoidance.

Mobile motes and objects in the environment exert virtual repulsive force. The vector of that force is calculated and given as direction to the mote's mobility system. In this way motes seem to push away one another and being pushed by obstacles of the environment.

The motes will keep moving till the static equilibrium state is reached. It's the state where every mote's control vector value is 0. Then parameter could be chosen accordingly, so every mote maintains a desired overlap of its own and neighboring motes sensing range.

This approach does not require models of the environment or communication between motes. Motes cover the area uniformly, using a distance sensor which allows every mote to calculate the control vector and move to new position till it reaches static equilibrium [10].

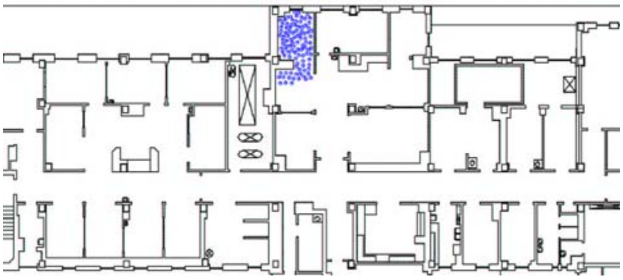

Fig. 3 Initial network configuration

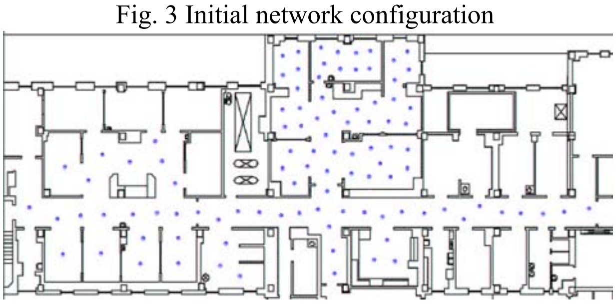

Fig. 4 Final Configuration

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