IJCSE International Journal of Computer Sciences and Engineering Open Access
Review Paper Volume-4, Issue-6 E-ISSN: 2347-2693

A Review on Sweep Coverage in Wireless Sensor Networks

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www.ijcseonline.org

Received: May/26/2016 Revised: Jun/06/2016 Accepted: Jun/18/2016 Published: Jun/30/ 2016

Abstract— There are lots of applications where only periodic monitoring (sweep coverage) is sufficient instead of continuous monitoring. The main goal of sweep coverage problem is to minimize the number of mobile sensor nodes moving with uniform velocity required to guarantee coverage as per given sweep time. In the sweep coverage scenario, deployment of static sensor nodes may partially solve the purpose but it suffers from poor efficiency and unnecessary extra overhead. Moreover, static sensor network suffers from static sink neighborhood problem in which the sensors which lie near to the sink node dies due to which the sink disconnects from rest of the network.

Keywords— Sweep coverage; Approximation algorithm; Mobile sensor; TSP; MST; Euler tour; Tessellations

I. INTRODUCTION

Coverage in wireless sensor networks (WSNs) has been an active and important research topic. Coverage problem is of two type viz static coverage and sweep coverage. Static coverage problems are broadly categorized in three types depending on applications. First one is point coverage where a set of discrete points is continuously monitored, second one is area coverage where the given area is continuously monitored, and third one is barrier coverage where specified boundary is continuously monitored by sensor nodes.

But there are typical applications where only periodic patrol inspections are sufficient instead of continuous monitoring like in traditional coverage. This type of coverage is called sweep coverage. In the sweep coverage scenario deployment of static sensor nodes may partially solve the purpose but it suffers from poor efficiency and unnecessary extra overhead. Moreover, static sensor network suffers from static sink neighborhood problem in which the sensors which lie near to the sink node dies as they have to relay the data of other nodes which consumes more energy due to which the sink disconnects from rest of the network. Sweep coverage problems are broadly categorized in three types. First one is point sweep coverage where set of discrete points are to be periodically covered, second one is area sweep coverage where whole of the given area is to be periodically covered, and third one is barrier sweep coverage where specified boundary is periodically monitored by mobile sensor nodes. The main goal of sweep coverage problem is to minimize the number of mobile sensor nodes moving with uniform velocity required to guarantee sweep coverage as per given sweep time.

Rest of the paper is structured as follows: In section II, the literature review is presented. In section III, types of Sweep Coverage are discussed. The conclusion and Future work are presented in section IV.

II. LITERATURE REVIEW

In paper [2] authors define the coverage problem in Wireless Ad-hoc Sensor Networks from several points of view including deterministic, statistical, worst and best case, and present examples in each domain. They combine computational geometry and graph theoretic techniques, specifically the Voronoi diagram and graph search algorithms and proposed an optimal polynomial time algorithm for solving for best and worst case coverages.

Authors in paper [3] presents and analyzes a variety of regular deployment topologies, including circular and star deployments as well as deployments in square, triangular, and hexagonal grid.

In paper [4] authors proposed to deploy a mixture of mobile and static sensors to construct sensor networks to provide the required uniform sensing service in harsh environments while maintaining a relatively low cost. They proved this is a NP-hard problem and designed a bidding protocol to assist the movement of mobile sensors. In the protocol, static sensors detect coverage holes locally by using Voronoi diagrams, and bid for mobile sensors based on the size of the detected hole. Mobile sensors choose coverage holes to heal based on the bid.

Authors in paper [5] study the problem to maximize WSN's lifetime (in terms of rounds) while maintaining both discrete target coverage and network connectivity which not only provides satisfied quality of service in WSNs, but also presents more options and challenges to design an energy efficient sensor scheduling. They also study the relationship between network connectivity and target coverage and introduce a generic condition to guarantee network connectivity, design a round-based distributed algorithm to coordinately determine sensors sensing range based on different relations between transmission range and maximal sensing range.

In paper [6] authors defined the concept of k-barrier coverage and derived several key results such as the optimal number of sensors needed to achieve k-barrier coverage, and efficient algorithms to determine whether a given belt region is k-barrier covered or not.

Authors in paper [7] present a novel sensor deployment algorithm, called the adaptive triangular deployment (ATRI) algorithm, for large-scale unattended mobile sensor networks. The ATRI algorithm aims at maximizing coverage area and minimizing coverage gaps and overlaps by adjusting the deployment layout of nodes close to equilateral triangulation. The algorithm only needs the location information of nearby nodes, thereby avoiding communication cost for exchanging global information. The simulation results show that the ATRI algorithm achieves a much larger coverage area and smaller average moving distance of nodes than existing algorithms.

In paper [8] authors present a novel sweep coverage algorithm for systems with dynamic POIs, relying on a virtual 3D map of local gradient information to guide the movement of mobile nodes. Their algorithm is fully distributed and can achieve performance close to the optimum (i.e., the "ideal" sweep coverage).

Authors in paper [10] proposed a sweep coverage mechanism to keep the patrol times of mobile nodes approximate to one another. In simulation, various moving speeds and waiting times of mobile nodes are considered.

In paper [12] authors propose a distributed algorithm for the autonomous deployment of mobile sensors called Push & Pull. According to their proposal, movement decisions are made by each sensor on the basis of locally available information and do not require any prior knowledge of the operating conditions or any manual tuning of key parameters. They formally prove that, when a sufficient number of sensors are available, their approach guarantees a complete and uniform coverage.

Authors in paper [13] deployed mobile sensors in monitored area to provide sweep coverage of POIs. Two algorithms, MinExpand and OSweep, are designed and evaluated to use fewer mobile sensors to complete the sweep coverage task. The simulation results show that the algorithms can substantially reduce the number of mobile sensors to achieve the sweep coverage compared with state-of-the-art algorithm, CSWEEP.

Authors in paper [14] discussed the problem of determining the minimum number of required sensors for given sweep coverage requirements. They prove that this min-sensor sweep-coverage problem is NP-hard and it cannot be approximated within a factor of 2. Accordingly they propose a general centralized algorithm, GSWEEP, with constant approximation ratio 3 for this problem. They further design a distributed sweep algorithm, DSWEEP, which cooperates sensors to provide efficient sweep coverage for given POIs and their sweep period requirements with the best effort.

Authors in paper [16] considered the discrete unit disk cover (DUDC) problem, where a set P of n points and a set D of m unit disks in the 2-dimensional plane are given, the objective is (i) to check whether each point in P is covered by at least one disk in D or not and (ii) if so, then find a minimum cardinality subset $D* \subseteq D$ such that unit disks in D∗ cover all the points in P. They provide an 18-factor approximation algorithm for the DUDC problem. The running time of the proposed algorithm is $O(n \log n + m \log m + mn)$.

Authors in paper [17] considered the problem of covering a set of line segments with minimum number of sensors. The problem is shown to be NP-hard. An O(nlogn) time 12-approximation algorithm is proposed for a special case where the line segments are axis-parallel. It is further shown that an 8-approximation result can be obtained in $O(n^2)$ time.

Authors in paper [19] have discussed two kinds of sweep coverage problems in wireless sensor networks, viz point sweep coverage and area sweep coverage. Their proposed algorithm has achieved the best possible approximation factor 2 for the point sweep coverage, where each mobile sensor node visits every POI. Modification of the algorithm is proposed to extend lifetime of the mobile sensors and for sweep coverage in the presence of obstacles, and failure of mobile sensors. The simulation results on point sweep coverage show that the proposed algorithm performs better in terms of the number of mobile sensors to achieve point sweep coverage compared to the existing sweep coverage algorithm MinExpand. They have introduced sweep coverage for a given area of interest (AOI) and proved that the problem is NP-complete. A $2\sqrt{2}$ -approximation algorithm is proposed in order to solve the problem for a square region.

III. SWEEP COVERGAE

A. *POINT SWEEP COVERAGE*

The definition of point sweep coverage is given below as on the paper [14].

Definition 1 (Point Sweep Coverage) Let U = {u_1, u_2, . . . ,u_n} be a set of discrete Point of Interest (POI) on a two-dimensional plane and S = {s_1, s_2, . . . , s_m} be a set of mobile sensors. A point u_i is said to be t_i point Sweep covered if and only if at least one mobile sensor visits u_i within every t_i time period. The set U is said to be globally point sweep covered by the mobile sensors of S if all $u_i \in U$ are t_i sweep covered. The time period t_i is said to be the sweep period of the point u_i.

Let us consider a set of POI on 2D plane containing n points. Let G = (V, E) be the complete graph with each point as a vertex and the line joining two points i and j on the plane as edge. The Euclidean distance d(i, j) is the weight w(i, j) of edge (i, j). Let v be the uniform speed of all mobile sensors and t be the common sweep period for the set of n points in V.

Definition 2 (Point Sweep Coverage Problem). The point sweep coverage problem is to find the optimal (minimum) number of mobile sensors to guarantee sweep coverage for all points in V. Li et al. in the [14] proved that the above point sweep coverage problem is equivalent to find TSP tour of G. A tour can be found on G using 'Metric TSP—factor 2' approximation algorithm [1] by the method of finding Euler tour from an MST of G.

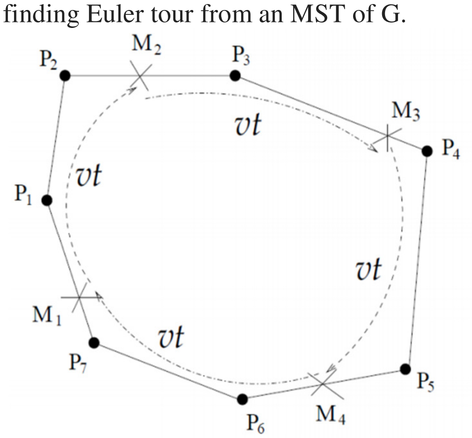


Fig. 1: The figure showing TSP tour for the POI, P_1,P_2,.........,P_7, and initial position of the mobile sensor nodes M_1,M_2,M_3,M_4 for sweep coverage of the POI.

Algorithm 1: Point sweep coverage

1: Find a TSP tour L of G by the method of finding Euler tour from an MST of G using 'Metric TSP-factor 2' approximation algorithm [1]

2: Partition L into $\left\lceil \frac{L}{vt} \right\rceil$ parts as shown in Fig. 1 and deploy $\left\lceil \frac{L}{vt} \right\rceil$ mobile sensors at all partition points, one for each.

3: Each mobile sensor node then starts moving at the same time along L in same direction (either clockwise or anti-clockwise).

B. AREA SWEEP COVERAGE

In area sweep coverage all the points of a bounded region must be covered at least once in a certain time period. Same strategy like point sweep coverage cannot be applied to solve the area sweep coverage since there are uncountable number of points in any bounded region. Here we are considering homogeneous mobile sensors with sensing range D. The mobile sensors can be considered as sensing disks with radius D, centering at it. The definition of area sweep coverage is given below as on the paper [19]

Definition 3 (Area Sweep Coverage) Let A be a given bounded AOI and S = {s_1, s_2, . . . , s_m} be a set of mobile sensors. A is said to be t area sweep covered if and only if each point of A is in the sensing disk of at least one mobile sensor in every t time period. The time period t is said to be sweep period of the area A.

Definition 4 (Area Sweep Coverage Problem) The area sweep coverage problem is to find the optimal (minimum) number of mobile sensors such that for a given time period t, each point of a given area A is t-sweep covered.

Although the area sweep coverage is different from point sweep coverage, but it can be solved using a solution of the point sweep coverage. Let us consider a point set P = {p_1, p_2, . . . ,p_k}, where each $p_i \in A$ such that a placement of static sensors at each point p_i covers A.

Lemma 1. The point sweep coverage of the set of points P on A guarantees the area sweep coverage of A.

Proof. Suppose we have a solution for point sweep coverage for the set of points P. Therefore at least one mobile sensor visits each point p_i at least once in every t time period. Since one static sensor at each p_i gives complete coverage of A (according to above assumption), each point of A is inside at least one sensing disk in every t time period. Hence the solution of point sweep coverage problem for P is also a solution of area sweep coverage problem for A.

Based on the above Lemma 1 we have proposed Area Sweep Coverage algorithm for area sweep coverage problem, where A is any given region. For this we first divide the given area using the concept of tessellations. We can tessellate the given area using any one of the three regular tessellations viz square, hexagon and triangular (see Table 1). In paper [3] concept of tiling is described. Gorain et al. in [19] have solved the problem of Area Sweep coverage by considering the area as square region and assuming that the side of the square is divisible by $\sqrt{2}$ D and tilling it with the square of edge length $\sqrt{2}$ D.

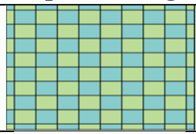
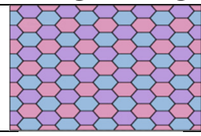
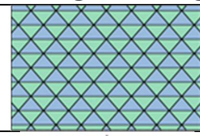
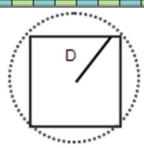
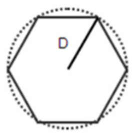
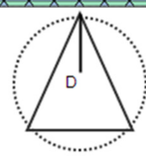
Square tilling	Hexagon tilling	Triangular tilling
		
		
Edge Length = $\sqrt{2}$ D	Edge Length = D	Edge Length = $\sqrt{3}$ D

Table 1: The table shows relation between edge length of tile to be used for tessellations and sensing range D of sensor.

Algorithm 2: Area Sweep coverage

1: Divide the area using the concept of tessellations (tilling)
2: Let P is the set of center points of each tile.
3:Apply Algorithm 1 to compute the number of mobile sensors required for sweep coverage for P.

IV. CONCLUSION AND FUTURE WORK

In this paper we have discussed two kinds of sweep coverage problems in wireless sensor networks, viz point sweep coverage and area sweep coverage. From the above discussion it is clear that the main goal of sweep coverage problem is to minimize the number of mobile sensor nodes moving with uniform speed required to guarantee sweep coverage as per given sweep time. As speed of mobile sensor nodes and sweep time is fixed therefore number of mobile sensor required for sweep coverage depends only on L (length of closed path) .

Sweep coverage is a purely new concept for sensor network monitoring. There are still many interesting problems not discussed. The problem of area sweep coverage is studied by Gorain et al. in [19] and they proved that the problem is NP-complete and $2\sqrt{2}$ -approximation algorithm is proposed in order to solve the problem for a square region using square tilling.

One significant extension of this problem is that the given region is any general Polygon and we need to do the Sweep Coverage for Area of the region. Other extension of this problem is that the given region is any general Polygon and we need to do the Sweep coverage for its boundary. In my future work, I plan to study these problems and obtain useful results.

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