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Area Coverage for Clustered Directional Sensor Networks using Voronoi Diagram

Selina Sharmin , Fernaz Narin Nur , Md. Abdur Razzaque
Green Networking Research Group
Department of Computer Science and Engineering
University of Dhaka, Dhaka-1000, Bangladesh
Email: {selinasf13, fernaznur}@gmail.com, razzaque@du.ac.bd

Md. Mustafizur Rahman
Department of Computer Science and Engineering,
University of Dhaka, Dhaka - 1000, Bangladesh
Email: mustafiz@du.ac.bd

***Abstract*—Area coverage is a fundamental research problem in Directional Wireless Sensor Networks (DSNs). Unlike omni-directional sensors, it is required to activate the sensor nodes along with their sensing directions in DSNs. Appropriate selection of sensing sectors that can maximize the area coverage is a challenging problem here. In this work, we develop a greedy algorithm for area coverage in clustered DSNs using Voronoi diagram. To improve the overall area coverage ratio in the network, the cluster head activates the directional sensors by considering the area coverage contribution of sensors in the Voronoi cells. The use of clustering and Voronoi cells reduces the computational complexity and increases the overall coverage ratio. The simulation experiement results show the efficacy of the algorithm over the state-of-the-art works it is compared to.**

I. Introduction

In recent years, Directional Wireless Sensor Networks (DSNs) become very popular and have attracted immense interests due to their promising platforms for many applications such as environmental monitoring, battlefield surveillance, health care etc. Unlike omni-diectional sensors directional sensors have limited angle of sensing range and the coverage region of a directional sensor is determined by both its location and its direction of sensing radius. This property of directional sensor ensures some advantages of using it in the environment such as increasing network life time, minimizing energy consumption, increasing spatial reusability etc. Sensors like video sensors, ultrasonic sensors, infrared sensors are examples of widely used directional sensors [1].

Area coverage is one of the fundamental coverage problem which reflects how well the environment is monitored. It is necessary to schedule the sensors to face a certain direction to maximize the coverage region. Again to cover a certain area if all the sensors are activate at a time, this will make huge energy loss. Since sensors are tiny battery powered equipment the sensors should activate in such a way that it will cover the region at the same time increase the network life time.

In this paper, our goal is to maximize the area coverage with minimum number of sensors in a randomly deployed DSNs well known as MCMS problem in literature. This problem is proved to be NP hard [2] in literature and greedy or heuristic solutions are proposed. Dividing the sensing sectors of each node into small grids the authors in [3], [4] try to minimize the number of active sensing nodes by reducing the overlapping area using virtual force [4] and centroid location [3] among nodes. Using distributed algorithms on voronoi cells to select active nodes and their sensing directions to cover a larger area in the voronoi cell the authors in [5, 6, 7], solve the area coverage problem. Normally sensor networks are dense and it is difficult to obtain the optimal field coverage since partial regions are not covered and some regions are overlapped. Moreover centralized solutions are difficult to obtain because it requires the overall scenario and on the other hand, distributed solutions are difficult to implement. Our previous work [2] proposes algorithms for area coverage using the advantages of clustering in an energy efficient way. However, the work did not considered the advantages of dividing the whole area into some cells and thus cannot provide a better solutions.

Concerning to area coverage although there are studies, the solutions are different. In this work, we focused on the coverage improvements of DSNs, taking the advantage of clustering in the environment and using the characteristics of Voronoi diagram. The major contribution of the paper are summarized as follows:

- We propose a novel Voronoi based Area Coverage solution (VAC) for a clustered directional sensor network using steerable directional sensors.
- Instead of giving responsibility to individual nodes, the cluster head (CH) has the responsibility to determine the active nodes with their sensing directions.
- Using the characteristics of Voronoi diagram, greedy approach is used to determine the active nodes by the CH. The approach decreases decision making complexity as well as computing overhead without knowing the global information.
- We evaluate the performances of the proposed VAC mechanism in ns-3 [8] and the results outperform state-of-the-art works.

The rest of this paper is organized as follows. We describe related works and motivation in Section II and Network model and assumptions in Section III. Our proposed mechanism is presented in Section IV and the simulation results are presented in Section V. Finally, we conclude the paper in VI along with future research direction.

II. Related Works

Studies related to DSNs coverage can be divided into three categories (1) target coverage (2) area coverage and (3) sensing or barrier coverage. Researchers related to the target coverage determine a subset of sensors to cover some specific targets or positions and the barrier coverage detects events crossing a barrier of sensors [1]. On the other hand, area coverage activates the sensors in such a way that a certain or full region falls under the sensing coverage [5], [6]. In this work, we provide solutions for area coverage for a DSNs.

Xiaofeng at. el. in [9] investigated the problems of connected coverage in directional sensor networks and proposed two efficient deployment patterns with guaranteed covering density and with respect to arbitrary non-crossing deployment patterns analyze their performance bounds. However, sometimes it is not rational to deploy nodes in a predefined pattern.

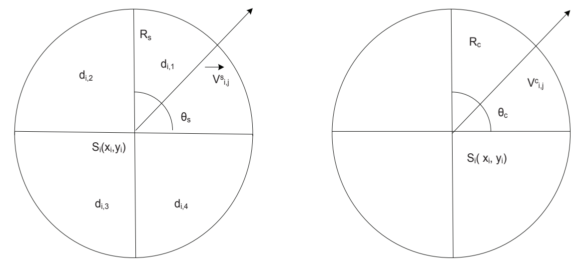
For solving coverage problems, some researchers use Voronoi-based method. In [5] the authors proposed the Voronoi based distributed approximation (VDA) algorithm that try to cover the Voronoi edges as more as possible using sensor nodes. Tien at. el. [6] use Voronoi-diagram to enhance the coverage ratio among overlapping nodes and propose distributed greedy algorithm without global information. Utilizing mobile and direction-rotatable sensors the authors in [10], enhance the overall field coverage in DSNs. Their algorithm makes sensors self-redeploy by utilizing the features of geometrical Voronoi cells. Presenting auto-rotation mechanism of Field of View (FOV) for each sensor node the authors in [11] maximize the coverage area in an interested region. However, this works fails to offer better coverage and higher network lifetime as it finds the overlapping region only for a circle.

The authors in [7], select the direction of the nodes based on voronoi vertices. Here they propose two algorithms: Intracell working direction (IDS) to enhance the region inside the cell and Inter-cell Working Direction Adjustment (IDA) to minimize the overlapping regions among neighboring nodes. Also to control the direction of sensors outside the boundary propose Out-of field Coverage Avoidance (OFCA) algorithm proposed here. In [3], in order to optimize the network coverage, the authors propose a coverage-enhancing algorithm based on overlap-sense ratio.

In literature, many area coverage algorithms have been proposed [2], [7], [3]. However, to the best of our knowledge, only a very few works utilize the benefits of clustering in the environment using the characteristics of Voronoi-diagram when selecting active nodes along with their sensing directions to solve area coverage problem for DSNs. In our proposed work, the active nodes are selected considering nodes covering area in the Voronoi-cell for a clustered DSNs and shows better results in the state-of-the art works.

III. Network Model and Assumptions

We assume a DSN composed of *N* directional sensor nodes S_1, S_2, . . . , S_n in a two-dimensional plane. The sensors are deployed with uniform random distribution in area *A*. The DSN has a sink node, to which all sensor devices send their sensed data in multi hop fashion. Each sensor S_i has a fixed and known location (x_i, y_i), determined by GPS or any other localization method. Each sensor device is uniquely identified by its ID which we assume an integer number. In terms of sensing sectors, sensing and communication radius all nodes are uniform in the network. For cluster formation we assume a clustering algorithm is running in the network([12]). A sensor node can be in either active or sleep state. From sleep state, a sensor node periodically wakes up and communicates with its cluster head to check the neighbor information and sensing coverage.



(a) Sensing model (b) Communication model

Fig. 1. Directional Sensor model

TABLE I
List of Notations

Symbol	Definition
N	The set of sensor nodes in the network.
S_i	The i^{th} sensor node 1≤ i ≤ N , S_i ϵ N.
ϕ_s	The set of sensing sectors of a sensing device.
ϕ_c	The set of communication sector of a node.
$d(S_i, S_j)$	Euclidean distance between sensors S_i and S_j.
p	The number of sectors.
$n^l_{i,j}$	l is a neighbour of node i in j_{th} sector.
$d_{i,j}$	The j^{th} sector of i^{th} sensor 1≤ j ≤ p.
Ω_i	The sector sorted list if i^{th} sensor.
ω	The number of cluster member sensor nodes.
Υ	The sensor sorted list of γ_i.
CH_m	CH member nodes.

Each sensor has p ($p >= 2$) sectors which are centered at the sensor node with a sensing radius r^s and the sensing angle $\Theta^s = 2\pi/p$. Here Θ^s is called the field of view(FOV) shown in fig 1(a) which is the maximum sensing angle. r^s is the maximum sensing radius and a sensor cannot sense anything beyond this radius. The j^{th} sector of the i^{th} sensor is denoted by $d_{i,j}$. At a time a sensor can works only at one sector. We serialize the sector starting from one. For example node S_i has four sectors $d_{1,1}$,$d_{1,2}$,$d_{1,3}$,$d_{1,4}$ (Fig. 1(a)).

Each sensor has a set of communication sectors or orientations. A sensor has some characteristics attributes for its communication sectors. The maximum communication angle is $\Theta^c(0 \leq \Theta \leq 2\pi)$ and the maximum communication radius is r^c. Typically, r^c is twice larger than the r^s.

The list of notations that we have used in this paper is given in Table I.

IV. Proposed VAC mechanism

We have proposed a Voronoi-based area coverage mechanism (VAC) for a clustered DSN. Each CH selects its member nodes along with their sensing directions based on the covering area in the voronoi cell. What follows next is the description of the proposed protocol.

In the process of active member node selection with their corresponding sector, each CH K first build the Voronoi diagram for its members in its working communication sector, as shown in Fig. 2. Next each CH K arranges the sectors of its member sensors in decreasing order based on the covered area in the voronoi cell. For this, the CH K measures how much area $(A_{i,j})$ of a member node has occupied in the voronoi cell for node's each sector and make a list Ω_i that contains the values $(A_{i,j})$ in decreasing order. For example, the list Ω_1 for node S_1 is Ω_1= $\{A_{1,1}$,$A_{1,2}$,$A_{1,3}$,$A_{1,4}\}$ (Fig. 3(a)) and Ω_1= $\{A_{1,3}$,$A_{1,4}$,$A_{1,1}$,$A_{1,2}\}$(Fig. 3(b)). Area $A_{i,j}$ can be calculated by knowing the coordinates $(x_i,\ y_i)$ of sensor, and the intersections of sensing sector boundary and cell edges. As all the informations are available to the CH, CH can easily find the covered area in the voronoi cell [2].

Based on the values of the list Ω_i, CH K takes decision to keep a node in active or sleeping state. From the list Ω_i for all $S_i \in CH_m$, CH K selects a node $d_{i,j}$ by checking the following condition

$$Overlap(d_{l,j}, d_{i,j}) \leq \delta, \quad \forall j \in \phi_s, l \in n^l_{i,j}, d_{l,j} \in \Upsilon \qquad (1)$$

Here the value δ is a threshold value which indicates the maximum acceptable overlapping among the neighbour nodes and $Overlap(d_{l,j}, d_{i,j})$ calculates the overlapping among the neighbourhood nodes ([2]). A CH K checks the condition 1 for each item of the list Ω_i serially and keep a node $d_{i,j}$ in active list Υ for which condition 1 is true. If condition 1 is false for all the entries of the list Ω_i for a node S_i the node will goes to sleep state. Finally CH activates the nodes of the active list Υ along with their corresponding sector. Note that, at the time of selecting a node $d_{i,j}$ using the list Ω_i, always priority goes to the sector which cover the largest area in the Voronoi-cell and a node can be selected only once for the active list Υ. The details of the process is summarized in Algorithm 1.

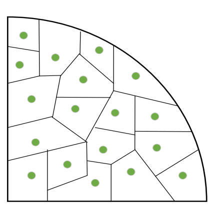
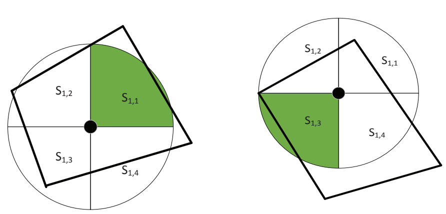


Fig. 2. Voronoi-diagram inside the CH for member nodes



(a) (b)

Fig. 3. Covered area inside the cell for different sectors

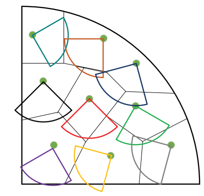


Fig. 4. After activating nodes in the CH communication sector

Algorithm 1 Active member selection at each node $i \in N$

```
input: S_i ∈ CH_m
a list Υ that contains the active sensors list with their sector numbers
Begin
for all S_i ϵ CH_m do
    Find A_{i,j} for each j ∈ φ_s, S_i ∈ CH_m
    make a list Ω_i sorting the value of A_{i,j} in ascending order for each d_{i,j} ϵ S_i
    for t = 1 to p
    take a A_{i,j} from the list Ω_i serially
    if condition 1 is true for d_{i,j} then
        Υ = Υ ∪ d_{i,j}
    else
        goto next A_{i,j}
    end if
    End
end for
```

Fig. 4 shows an example scenario after running the algorithm in a CH and the corresponding activated sensors along with their sectors.

V. Performance Evaluation

We evaluate the performance of proposed VAC mechanism using NS-3, a discrete event network simulator and compare proposed protocol with two state of art works NLAC [2] and IDA-OFCA [7]. Directioanl Sensors are uniformly deployed in a region of $1000 \times 1000 m^2$. For different experiments, we have varied the number of sensors from 200 to 1000. A clustering algorithm for DSN [12] has been used to form a clustered networks. In the simulation we have used AODV for routing and DCD-MAC[13] for medium access in the network. YansWifiPhy model is used for setting the channel properties such as the propagation delay model, data rate, delay loss model and other channel characteristics. For event generation, we use OnOff application type. The size of generated packet by the event is 512 bytes. Each simulation is run for 1000 seconds. For each graph data points the average result of 20 simulation runs is used.

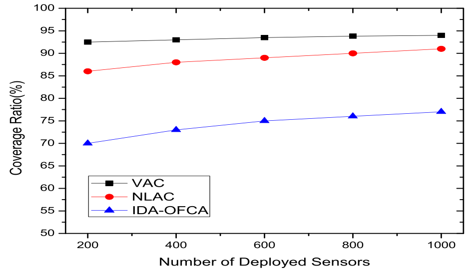


Fig. 5. Coverage percentage vs. number of deployed sensor devices

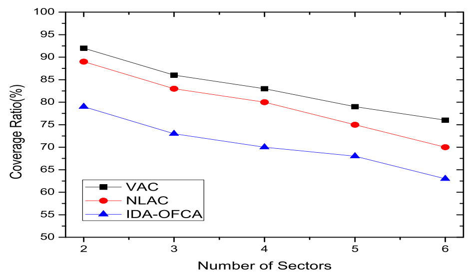


Fig. 6. Coverage percentage vs. number of sensing sectors

For the simulation we have examine the area coverage percentage for varying number of deployed sensors and sectors. The coverage percentage is measured as the ratio of total number of covered grids to the total number of grids in the terrain. From the graphs in Fig. 5, we find that the performance of our proposed VAC outperforms from the state-of-art works. Though NLAC use clustering mechanism to decide the active nodes, however our proposed work shows better results as it uses the advantage of Voronoi-diagram. On the other hand, IDA-OFCA takes totally distributed decision to select active nodes.

From the graphs in Fig. 6, we find that there is a substantial improvement in terms of area coverage percentage for VAC. This result is achieved because of, opposing to NLAC and IDA-OFCA, our algorithm use the advantages of clustering as well as the characteristics of Voronoi-diagram.

VI. Conclusion

In this paper, an area coverage mechanism is developed for clustered DSNs following special geometric features of Voronoi diagram. The simulation results show the performance improvements of VAC compared to state-of-the-art works. How to further improve the area coverage performance for a DSN with mobile nodes in an energy-efficient way is our future work to address.

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