COVERAGE IN A HETEROGENEOUS SENSOR NETWORK

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ABSTRACT
Wireless sensor network field has drawn attraction of researchers for its diversified applications. Due to the ad-hoc in nature of sensor network, conventional wireless network algorithms can not be applied directly. There are lot of problems which affect badly network performance and quality of service. Among these problems, lack of good coverage of network area is a major frustrating issue. Sensor network coverage issue becomes more complicated when there are different types of sensors exist in a same field. If the network nodes vary in their properties coverage problem becomes more complicated. In [9], the authors gave an upper and lower bound of coverage using Voronoi diagram. But they only considered a homogeneous network. Their solution becomes challenging for heterogeneous network. In our paper we give a solution to handle heterogeneous sensor network where sensors are not isotropic.

KEY WORDS
Heterogeneous sensor network, coverage, path finding, Voronoi diagram, Delaunay triangulation.

1. INTRODUCTION
Advances in wireless network technologies have created a new era where small sensor devices provide access to information anytime, anywhere as well as actively participate in creating smart environments. Sensors are deployed in remote battlefields for a surveillance application, for analyzing the weather conditions, for fire detection in forests, for pollution detection, for studying the traffic conditions and for planning efficient routes etc. There is a wide range of applications for sensor networks with differing requirements. It is important to maintain the network performance and the quality of services. Coverage is a very important metric to measure network performance. Due to the large variety of sensors and their applications, sensor coverage is subject to a wide range of interpretations. If the area is not covered properly by the deployed sensors or the sensor nodes are disconnected the whole network fails. Coverage formulation tries to find weak points in a sensor field and suggests future deployment or reconfiguration schemes for improving the overall quality of service of the network. If sensors having different ranges are deployed in the same field different types of sensor with different intensity level are deployed. It is important to know how many and what type of the sensors should be deployed to cover the whole area and where to deploy them. Determining the uncovered area and the network connectivity are also very important. Overall, these issues are very challenging and researchers are trying to provide standard comprehensive models.

In [9], the authors gave an upper and lower bound of coverage in a homogeneous network field using Voronoi diagram. But this is not applicable for heterogeneous network. In our paper we figured out the challenges and problems of a heterogeneous network and provided a solution to handle this problem. Our algorithm finds the path which is not covered by sensors, and also detects the required sensor types.

The rest of the paper is organized as follows: in Section 2 we describe some related work. In Section 3 we discuss preliminaries related to the coverage problem and heterogeneous network. Section 4 defines the problem and our approach to solve the problem. Finally, Section 5 gives the conclusion.

2. RELATED WORK
In this section we discuss some work related to the coverage problem in wireless sensor networks. The coverage problem can be classified under different objectives and metrics. The different approaches to the coverage problem includes deterministic or stochastic sensor deployment, homogeneous or heterogeneous sensing area, additional design constraints such as energy efficiency, minimum number of sensors that need to be deployed, or network connectivity [6]. Based on the objective, the coverage problem formulation varies to reflect the different assumptions and objectives. In [14] the authors provide a geometric analysis that relates coverage to connectivity and define the necessary conditions for a network covering a field of interest to be connected. The conditions for coverage and connectivity are derived based on the assumptions that the sensing area of each node is identical and circular, and the location of the nodes is known. The authors extend their algorithms for the case of probabilistic deployment, and also relax their assumptions to non-unit disk sensing areas, by approximating the real sensing area with the biggest
possible circular area included in the real sensing area. In [8], the authors study the problem of deterministic node placement in order to achieve connected coverage, that is, sense the field of interest with the minimum number of sensors, while keeping the sensor network connected. The authors assume that the sensing area of each sensor follows the unit disk model and consider sensors with identical sensing areas. Some path planning and coverage algorithms are discussed for mobile robots in [1], [3] and [5] using generalized Voronoi diagrams.

In [10] the authors study the problem of deterministic coverage under the additional constraint that each sensor must have at least \(k\) neighbors. They proposed a deployment strategy that would maximize the coverage while the degree of each node is guaranteed to be at least \(k\); under the assumption that the sensing range of the sensors is isotropic.

In [12], the authors study the problem of coverage, as a path exposure problem. Using a generic sensing model and an arbitrary sensor distribution, they propose a systematic method for discovering the minimum exposure path that is the path along which the network exhibits the minimum integral observation ability. In [10], the authors provide a decentralized and localized algorithm for calculating the best coverage. Authors in [11], study the problem of stochastic coverage in large scale sensor networks. The authors provide the fraction of the field of interest covered by \(k\) sensors, the fraction of nodes that can be removed without reducing the covered area as well as the ability of the network to detect moving objects. The results presented in [11] hold only for randomly (uniformly) deployed networks and under the assumption that the sensors are identical. It suffers for heterogeneous sensor network.

Meguerdichian et al. [9] used the properties of the Voronoi diagram and Delaunay triangulation to find the coverage. They gave the upper and lower bound of the coverage and found the maximum breach and the minimum support for the network coverage. But as heterogeneous sensor network nodes vary in their properties and the sensor nodes are ad-hoc in nature, it is not possible to apply their technique directly [9]. In Section 4, we describe the problem and show how modified Voronoi diagram and the Delaunay triangulation serve in a heterogeneous sensor field.

Figure 1 shows an example of a Voronoi diagram for a set of randomly placed sensors and the corresponding Delaunay triangulation. \(I\) and \(D\) are starting and destination points of a path which follows the Voronoi edges in that diagram [9].

**3 PRELIMINARIES**

**3.1 Using Voronoi Diagram and Delaunay Triangulation for Path Finding in Sensor Network**

A heterogeneous sensor network is characterized by the difference in node properties. Node can be different in their architecture, application, mobility, energy level, sensing and transmitting ranges. Heterogeneous sensor nodes vary in their properties and the sensor nodes are ad-hoc in nature.

The Voronoi diagram has been applied to find the solutions in many problem domains. Aurenhammer gave a short survey in his paper [2]. By definition, in two dimensional Euclidian space, the Voronoi diagram of a set of discrete points partitions the plane into a set of convex polygons such that all points inside a polygon are closest to only one point. This construction effectively produces polygons with edges that are equidistant from neighboring points.

There is another structure that directly related to Voronoi diagrams by its duality called the Delaunay triangulation [2], [4]. The Delaunay triangulation can be obtained by connecting the points in the Voronoi diagram whose polygons share a common edge. It has been proved that among all possible triangulations, the Delaunay triangulation maximizes the smallest angle in each triangle. A Delaunay triangulation must satisfy the empty circle property, which states that there is a circle containing the end points of a Delaunay edge and no other points (edges). Therefore, neighborhood information can be extracted from the Delaunay triangulation since points that are close together are connected.

Like Meguerdichian et al. [9] we use the properties of the Voronoi diagram and Delaunay triangulation to find the coverage. But as our heterogeneous sensor network nodes vary in their sensor area and energy levels it is not possible to apply their technique directly [9]. In Section 4, we describe the problem and show how modified Voronoi diagram and the Delaunay triangulation serve in a heterogeneous sensor field.

**3.2 Some Definitions**

We construct Voronoi diagram for a heterogeneous sensor set \(S\) whereas, we assume the location and the sensors’
sensing ranges of the sensors are known. Suppose $A$ and $B$ are two sensors. They might be of similar types or they may be different types. Voronoi diagram is independent of their types as in a Voronoi cell all points will be the closest to a point.

**Definition 1:** Now, $A$ and $B$ will be the neighbor sensors if the Voronoi cells containing $A$ and $B$ have common edge. There will be exactly one Voronoi edge between one pair of sensors nodes.

**Definition 2:** We call each sensor node with its circle of area representing sensing range varying with its energy level, wide nodes.

**Definition 3:** It is possible to replace all sensors with wide nodes and then we determine Delaunay triangulation based on replaced sensor network of $S$. We call it Modified Delaunay Triangulation or $MDelT(S)$.

**Definition 4:** It is possible to replace all sensors with wide nodes and then we determine Voronoi diagram based on replaced sensor network of $S$. We call it as Modified Voronoi Diagram or $MVoronoi(S)$.

**Notation:** We denote the area as circle which represents the intensity level of a sensor. We assume the radius of this circle proportionately varies with the intensity level.

### 4. OUR APPROACH

#### 4.1 Problem Definition

**Lemma 1.** As Delaunay triangle maximizes the minimum angle, the edge between $A$ and $B$ will be the shortest distance between two sensors. There can not be any sensors between $A$ and $B$.

**Proof:** By the geometrical properties of Voronoi diagram and Delaunay triangulation it is directly proved. □

We remember, a Voronoi edge is the perpendicular bisector of the edge of a Delaunay triangle according to their dual property and Delaunay triangulation satisfy empty circle property [5]. According to this property,

$$\text{dist}(A, B) \leq \text{radius}(A)+\text{radius}(B)+k, \text{ where } k \geq 0 \quad (1)$$

where as, $A$ and $B$ are the end points of their Delaunay edge and sensor node $A$ is of energy level $\xi_a$ and $B$ is of energy level $\xi_b$. Besides, $\text{radius}(A)=\xi_a$ and $\text{radius}(B)=\xi_b$.

Now there may be three different observations. **If $P$ is on the Voronoi edge of neighbor sensors $A$ and $B$, it may have some possible situations if we ignore the intensity level of sensor types.**

**Case 1.** $P$ is the point in their intersection region of the circles of intensity level of sensor $A$ and $B$. Figure 3. (a) illustrates Case 1.

**Case 2.** $P$ is the intersecting point of the circles of sensing range of sensor $A$ and $B$. Figure 5 illustrates Case 2. Figure 3. (b) illustrates Case 2.

**Case 3.** $P$ is on any of the circles of sensing range of sensor $A$ and $B$. Figure 6 illustrates Case 3. Figure 3. (c) illustrates Case 3.

**Case 4.** $P$ is neither of the circles of sensing range of sensor $A$ and $B$. Figure 7 illustrates Case 4. Figure 3. (d) illustrates Case 4.

It can be easily observed that, **Case 2, 3 and 4 are consistent with the properties of Voronoi diagram and Delaunay triangulation. But Case 1 violates Voronoi diagram’s property if we ignore the circle of intensity level.**

**Lemma 2.** $MVoronoi$ and $MDelT$ maintain Voronoi and Delaunay triangulation properties.

**Proof:** We replace wide nodes with points. Now, $MVoronoi$ have the properties of Voronoi and $MDelT$ have the properties of Delaunay Triangulation. □

Now, we build $MDelT$ and their corresponding $MVoronoi$ based on a heterogeneous sensor network $S$ of wide nodes. Here we build $MVoronoi$ based on the endpoints of the
circles of sensor nodes. Then, if wide nodes representing sensor A and B are the vertices of $\text{MDelT}(S)$, $XY$ separates the plane into two halves based on points $r_1$ and $r_2$ maintaining the Voronoi diagram properties. Figure 4 describes the $\text{MVoronoi}$ separating wide nodes.

Figure 4. $\text{MVoronoi}$ edge $XY$ separates plane based on point $r_1$ and $r_2$.

**Theorem 1.** A finite area of a heterogeneous sensor network with different types of nodes can be represented by a bounded Voronoi Diagram and Delaunay triangulation independent of the network.

**Proof:** The proof is direct by Lemma 1, 2 and equation 1. □

### 4.2 Cost function calculation

To more accurately model the intensity level of a sensor on edge, we first calculate the average range along the edge to the sensor. In [33] the authors only considered the sensor distance from the Voronoi edges. But Voronoi edge is infinite. So, the distance is accomplished by taking the integral from the edge to the sensor.

Figure 5 shows that, The sensor impact for point $P$ on $\text{MDelT}$ edge $XY$ can be more accurately calculated by taking line integral of sensor $B$ which represents $\text{weight}(XY, B)$ [13].

Then, $\text{weight}(\text{edge, point}) = \frac{\text{MIN}_\text{pt int} \sqrt{\text{lowest} \_ \text{dist} \times \text{lowest} \_ \text{dist}} + \text{x} \times \text{x} \text{edge} \_ \text{length}}{\text{MAX}_\text{pt int}}$.

Where as, $\text{MAX}_\text{point} = $ distance from one end of the edge to the perpendicular projection of the sensor on the edge.

$\text{MIN}_\text{point} = $ distance from the other end of the edge to the perpendicular projection of the sensor on the edge.

$\text{lowest} \_ \text{dist} = $ minimum distance between the edge and the sensor.

In Figure 5, $\text{XP}$ is the $\text{MAX}_\text{point}$, $\text{YP}$ is the $\text{MIN}_\text{point}$, $\text{BP}$ is the $\text{lowest} \_ \text{dist}$ between edge $XY$ and the sensor $B$.

The algorithm is now very simple as follows:

**Algorithm 1. Finding the lowest coverage path in sensor network.**

We give another straight and brief algorithm to find the location and the minimum intensity level of sensor covering the area as follows:

**Input:** edge $XY$ with $\text{weight}(XY, A)$ and $\text{weight}(XY, B)$ and $A$ and $B$ sensors with location and their intensity levels.

**Start**

Step 1: $k$ distance calculated from equation 1.

Step 2: If $\text{weight}(XY, A) = \text{weight}(XY, B)$

deploy sensor at the intersecting point of $XY$ and $AB$ with the level equal to radius$>> k/2$.

else

If $\text{weight}(XY, A)\neq \text{weight}(XY, B)$,
deploy sensor at the mid point of the intersections of the perimeters of the sensor $A$ and $B$ along the edge of $AB$ with the level equal to radius$>> k/2$.

**End.**

**Algorithm 2. Finding the place of deploying sensor.**
4.3 Analysis of the Algorithm

The maximal path with the lowest coverage, determines the path along the Voronoi edges with low impact on sensors. It can be computed easily which region of the plane is less covered. We can deploy sensors more in that area to improve the coverage.

Even we can place the sensor covered \( k \) distance from solving equation 1 combining Case 2, 3 and 4 with our model. We can detect the point of deployment and at least required energy level of sensor.

Given \( n \) sensors, the generation of the Voronoi diagram have \( O(n \log n) \) complexities. For \( n \) points, vertices and edges in the Voronoi graph are both \( O(n) \). So, the resulting graph used in the search phase of the algorithm is \( O(n) \) in terms of the edges. Therefore, the algorithm has a complexity of \( O(n \log n) \).

5. CONCLUSION

Heterogeneous sensor network is more complicated due to the variation in node properties. In [9], Meguerdichian gave an upper and lower bound of a homogeneous network field using Voronoi diagram. In our paper we give a solution to find the low covered area using Voronoi diagram for a heterogeneous sensor network. We give an algorithm to find the uncovered area where sensors have different sensing ranges.

REFERENCES