Coverage Hole Detection Algorithm for WSN

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Abstract —Sensing coverage problem is due to random deployment, quick energy depletion of tiny devices and node failure in the field of interest. Sensor coverage reflects the quality of measurement on the real-time application. In this paper, we derive optimal conditions for connectivity and coverage in WSNs. The existing work focuses on the random or uniform sensors distribution and acclimates the geographic greedy routing for data transmission. This paper follows a 2D Gaussian distribution and gives a framework for coverage. A distributed algorithm is proposed in this paper which has three phases: in the first phase, detection of coverage hole based on Hamiltonian cycle, the cycles that are optimal and borders same boundary hole as other cycles are determined in the second phase. In the final phase, restoration method to fill the coverage holes. A simulation result shows that coverage area increase due to Gaussian distribution and presence of a coverage hole is below 0.3%. It also shows that optimal coverage holes cycles bordering same boundary hole reduce packet loss by 30%.

Index Terms—Coverage area problem; 2D gaussian distribution; coverage hole; hamiltonian cycle; geographic greedy routing.

I. Introduction

A randomly distributed tiny devices constitutes Wireless Sensor Network (WSNs), these tiny devices are equipped with a signal processor, computational, memory, data transmissions and power supply unit. Self-governing tiny devices have the ability of sensing, gathering, processing, and transmitting processed data to the sink node. However, the constrained sensor network has several design issues namely coverage and lifetime. The surveillance of specified field of interest and transmitting sensory data accurately to the sink is referred as coverage. However, random deployment of tiny devices cannot ensure the required coverage of the field of interest and quality of coverage. There are several challenges for solving the coverage problems in WSNs such as deployment pattern, types of a sensor node, dimension of the monitoring area, and a centralized or distributed approach. In deterministic deployment pattern, the tiny devices are placed in pre-computed locations of monitoring area. However, the inaccessibility region such as tough terrain, it is difficult to compute the locations tiny devices, and it is difficult to have homogeneity of tiny devices in the entire network. The nodes are deployed in the two-dimensional monitoring area. The coverage area problem can be solved through a centralized or distributed approach. The global information of a network is gathered and executes coverage area avoidance algorithm at one sensor node in a centralized approach. In the distributed approach, a node collects the sensory data locally and executes coverage area avoidance algorithm. The connectivity and coverage are one of the circumstances for reliable data transmission. An effective approach to solving coverage area problem results in optimization of resources in a sensing field.

In the literature, there are several approaches for solving coverage problems based on computational geometry such as Voronoi diagram, novel edge-based, and vertex-based, and multiplicatively weighted Voronoi (MW-Voronoi) diagram [1]-[5] are commonly used techniques to resolve the coverage area problems in WSNs. The authors in [6] have proposed a probabilistic approach to determine the sensing range of sensors to cover a set of targets. It uses a sleep wake-up scheme to turn on and off the communication radios to save the energy. The Authors in [7] determines sensor node's sensing range based on the probabilistic approach to distribute sensors to maximize the coverage area. The coverage probability is enhanced by moving tiny devices from a overlapped covered area of Field of Interest (FoI) to unconcealed field of interest in an iterative way [8]. The proposed work emphasizes only on the coverage of the FoI and ignores the network connectivity. However, the coverage and network connectivity are ingredients of quality of sensing.

II. Literature Survey

In this section, summarize the recent research works on coverage and connectivity issues in WSNs. Cluster-based deployment pattern was proposed to cover the field of interest, the coverage holes are categorized into location-based, range based and connectivity based coverage holes. To discover the localized coverage holes, Delaunay triangulation's and Voronoi diagram based computational geometry approaches are used [9]. Shakkottai *et al.*, [10] determined required number of sensor number to cover its one-hop targets and have one hop connected sensor network.

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Further, Authors in [11] have proved that the required number of the active sensor node to cover a set of the target is independent of transmission and sensing ranges of the sensor node. In literature, there are two types of the coverage model namely probabilistic coverage and binary coverage model. In binary coverage model, if the target is covered by a sensor node then the binary value is set to 1 otherwise set to 0. In probability coverage model, if the target is covered by sensor and the sensing ranges of its neighbours then there is no coverage hole problem [12]. However, the absolute location of tiny devices is required to determine the coverage probability and coverage probability does not reflect the actual behaviour of tiny devices.

The coverage holes are discovered based on relative distances between neighbouring sensors [13]. Only events at the border of the field of interest are monitored by tiny devices. To determine border nodes and its effects, the authors in [14] used Voronoi diagram. A node is called as border node if it is not present either in the sensor node's sensing region or polygon region of Voronoi. Based on Rips complexes, decentralized schemes are proposed to determine the intersection of coverage in [15]. To determine the precise location of coverage holes Authors in [16] adopt nerve complex and Vietoris-Rips complex. The connectivity of the graph is constructed using the nerve complex and Vietoris-Rips complex to extract the characteristics of coverage and coverage holes in the networks. Similarly, Authors in [17] acclimated model contour graph and plane characteristics. Using connectivity knowledge and redundancy nodes in the network, the coverage holes are detected.

Onete *et al*., [18] relates the coverage holes to Hamiltonian cycle in the network and present a new technique to identify coverage hole in the network by Hamilton cycle in its network graph. The author uses the mesh-links matrix to determine Hamiltonian circuits in an undirected graph. Route packets around coverage holes without making the graph as planar, Petrioli *et al*., [19] proposed a Load-Balancing Algorithm. The algorithm has an ingredient of geographic routing, awake a sleep scheduling, and elimination of dead-end nodes. To avoid connectivity holes, the algorithm selects the relay node that is in the opposite direction of the destination to forward packets. Various coverage problems in Wireless Sensor Networks (WSNs) are analyzed thoroughly in [20]. Authors analyzed the various coverage problems in line with nodes deployment pattern, the model used for sensing, type of targets and characteristic of the field of interest to be monitored. Authors also proposed an algorithm that moves the redundant node to uncovered monitoring area with aid of node mobility. To determine the probability of connectivity and coverage between the source and destination Authors in [21] proposed a queuing network model based on virtual grid clustering.

The necessary conditions for coverage with connectivity are derived for the clustered network. To satisfy coverage and connectivity requirements in the post-deployment phase. Sahoo *et al*., [22] proposed a distributed algorithm that relocates nodes from the overlapping area to coverage hole region. Set of mobile nodes that have better coverage degree are selected from overlapping area, without annoying coverage and connectivity of the network, the mobile nodes are relocated to coverage hole region to maximize the coverage probability.

Kurt *et al*., [23] developed scheme that re-configures network and dynamically changes sensing a range of node to maximize coverage and connectivity in the irregular monitoring area. Authors also developed a scheme to determine the optimal nodes location to enhance the coverage and reduce the area of overlapped. The coverage ratio has a direct impact on network lifetime and energy consumption of node. To determine the required number of sensors for a particular Field of Interest authors in [24] proposed scheme that determines the effective sensing area with an optimal number of sensor nodes. In this scheme, the author have assumed binary disc sensing model, the precise geometry of the monitoring region is considered and sensing range of the sensor is set to width of the monitoring region to determine the effectual sensing area. Further, value of the effectual sensing area is used to find the critical sensor density (CSD) essential to accomplish an expected coverage ratio in a field of interest with a stochastic deployment.

III. PROBLEM STATEMENT

Determine the presence of coverage holes triangular and non-triangular when a certain field of interest is covered by a minimum set of k nodes, $K \epsilon S_n$. Formally, it is pretended that there are n tiny devices $S_1, S_2 ... S_n$ a field of interest have set of targets $T_1, T_2 ... T_m$ and each sensor node have connectivity to least one or more other nodes.

IV. PROPOSED ALGORITHM

The proposed algorithm consists of four phases: 1) Discovery of Neighbour 2) Hole Boundary Nodes Discovery 3) Hole Discovery 4) Cycle Selection.

The detailed pseudo code for the Algorithms can be found in https://github.com/Drvenkatesh/Gaussian-Distribution-based-Coverage-Hole-Detection-Algorithm-for-Wireless-Sensor-Networks

Algorithm 1 Coverage-Hole Border Detection ()

```
call FindNeighbours nodes
call HoleBoundary nodes
call Initiate nodes
call SelectCycle nodes
call Communication_Void_Restoration
```

A. Discovery of Neighbor

The first phase of the proposed algorithm. Each node calculates the distance between all other nodes. If the distance of nodes is within its transmission range, then they are considered as its *1-hop* neighbour. $G_1(V_i, E_i)$ is a *1-hop* neighbour graph, where V_i denotes set of *ids* of its *1-hop* neighbours and E_i denotes set of all edges between its *1-hop* neighbours. Using *1-hop* neighbours information, it is possible to discover *2- hop* neighbours. Each *1-hop* neighbours sends and receives the beacon packets to builds its *2-hop* neighbour graph. Let *1- hop* node *i* receives a beacon packet from all of its neighbour. A set of *1-hop* neighbour that receives a reply from all of its neighbours constitutes a *2-hop* neighbour graph $G_2(V_i, E_i)$. Note that beacon packets that are received from distinct node *id* are considered for *2-hop* neighbour graph and duplicated *ids* are discarded. The procedure to discover neighbour discovery is given in function *findNeighbours.*

B. Hole Boundary Nodes Discovery

The second phase of the proposed algorithm is to determine the node is hole-boundary node or not, each node knows its *1-hop* and *2-hop* neighbours. The hole boundary or non-hole boundary nodes are determined based on the Hamilton cycle. The internal node (Id_i) that have less than three neighbours or absence of a Hamilton cycle in its neighbour graph $G_i(V_i , E_i)$ (where G_i , $i=1, 2$) is considered as a coverage-hole border. Otherwise, it is a non-coverage-hole border node. In the new graph, the existence of Hamilton cycle is verified to regulate fence node is a coverage-hole border or not. The pseudo code to determine node is a coverage-hole border or not is shown in function *holeBoundary.*

C. Hole Discovery

In the previous step, the node of the graph is identified as hole boundary node or non-boundary node, hole boundary node broadcast its status to its *1-hop* neighbour nodes through the status message. The status message contains *seq_num* and *m_type* where *seq_num* represent *ID* of the node that have received and forwarded the status message to its neighbours. To begin the process, hole boundary node that does not any other hole boundary node as its neighbour or *ID* of hole boundary node is minimum among all its hole boundary node is selected as a beginner. The beginner knows its *1-hop* neighbour nodes and classified as fence nodes, non-hole internal nodes and hole boundary nodes. Beginner node construct status message with *seq_num* is equal to beginner *ID*s and set message *m_type* as *0* to indicate it is hole boundary node. *1-hop* neighbour nodes of a beginner will receive this message. If *1-hop* neighbour node is non-hole boundary fence node then it will discard the message. Similarly, if *1-hop* neighbour node is non coverage-hole border internal nodes then they broadcast with probability (*1- p*) and set the message *m_type 0*(which indicates the last node is a coverage-hole boarder node) or discard this message in this iteration. When *1-hop* neighbour nodes that are (other than non-coverage-hole border fence and non-coverage-hole border internal nodes) coverage-hole border node accept this message, it will forward the status message (if its message is new) after appending its *ID* to *seq_num* and set *m_type* as *1* (which indicates the last node is coverage-hole border nodes). If the non-coverage-hole border node obtain the message with *m_type 1* and forward by setting *m_type* is equal to *2* (which indicates the last two nodes are non-coverage-hole border nodes), (*1-2p*) is the probability of forwarding. The non-coverage-hole border that receives a status message with *m_type* as *2* will discard this message. Every coverage-hole border node will broadcast the status message by adding its *ID* and setting m type appropriately. The nodes that receive status message verifies message to check whether the message is fresh or old if so, it stores the status message. From stored messages, a node verifies the presence of cycle by verifying first set of *ID* in *seq_num* and last set of *ID* in *seq_num* of two status messages. If the first set of *ID* in *seq_num* are a same and last set of *IDs* are disparate and they are not neighbours then it is affected to be cycled. This process repeats at the node to check the presence of a new cycle, at end of this step their set of the cycle is discovered.

D. Cycle Selection

In the previous step, a hole boundary node discovered one or more cycles iteratively, and check the newly determined cycle is different from existing cycles or the same as before. The discovered cycle must be minimum and have a hole boundary node as a border. If the cycle is not minimum or not border hole boundary node then analyse these cycle to select the best cycle. The analyze of the cycle is done in this step. For each node in the cycle, determine set of the node that is *1-hop* or more than *1-hops* away and *2-hop* or more than *2-hops* away, it is represented as DS_1 and DS_2 respectively. N_i^1 and N_i^2 represent set of *1-hop* and *2-hop* neighbour of node *i*. To determine newly determined cycle borders same hole boundary as another cycle that is determined earlier. Find the intersection of DS_1 and N_i^1 for the old cycle. Similarly, find the intersection of DS_2 and N_i^2 for the new cycle, it is found that nodes in the new cycle are same as earlier cycle and border same hole boundary node and it has minimum path length. After such a set of cycles are determined, node position is adjusted to cover up the coverage hole in the networks.

E. Restroration Phase

Restoration from void node region is given in procedure *Communication_Void_Restoration*. A communication resto-ration algorithm is used for avoiding void region problem. During communication restoration procedure, void node stops the beaconing, changes its status and sends void node condition to its neighbourhood. The void node calculates new depth or horizontal movement. A neighbour node accepts the *void_node_announcement_message* updates neighbour table by removing the sender from its table and make sure that whether it is a void node or not.

In the restoration procedure depth adjustment method is adopted to relocate void nodes to the new location (depth) to continue the forwarding. Void nodes send the beaconing message that contains the information *seq_num*, *x*, *y*, and *z* location. The neighbour node that receives the beaconing message originated from the void node removes the entry from its routing table. It also ensures that node itself is in the void region or not by sending a *void_node_announcement_replay* message. Here void node is and it sends void announcement msg to neighbours. The node sends the replay to make sure that it is not in void region. After interval of time void node executes a *calculate_new_depth* procedure to compute a new location/depth. The *calculate_new_depth* procedure uses connectivity of hops information received through void node announcement replay message from neighbours that are not void nodes. The new location is determined as follows: the distance from nearest sink to a void node is larger than the distance from nearest sink to one of the neighbor.

V. Simulation Results

A. Performance Analysis

In Fig. 1, the parameter *p* and transmission range are kept constant. As shown cycle ratio is gradually increasing as a number of node increases, less number of nodes make the density of the nodes on less area and creates few holes. and decreases at some points due to the nodes are within the transmission range. The variations of nodes from 4.5 to 5.5 and 8 to 9 in *x-axis* due to the random deployment of nodes within transmission range. The relation between transmission range and cycle per ratio are in percentage as shown in Fig. 2. Number of nodes is set to 1000, area and transmission range are kept constant. There is rise in transmission range at node 11 and 14, which doesn't mean that they are vary a lot but they only vary in very small numbers. Ratio change for 11 and 13 is only about 1%, which is very less. The area percentage of coverage holes under distinct λ are shown in Fig. 3. Graph shows that the area of coverage holes with increasing number of sensor nodes. The coverage area is decreasing after relocating redundant neighbor nodes to coverage hole area. If all redundant nodes are relocated to eliminate coverage holes then new set of coverage holes are created in the network. The proposed paper adopts Gaussian distribution because coverage probability is much better than uniform distribution, therefore coverage hole area is decreasing. Fig. 3 illustrates impact of Gaussian distribution.

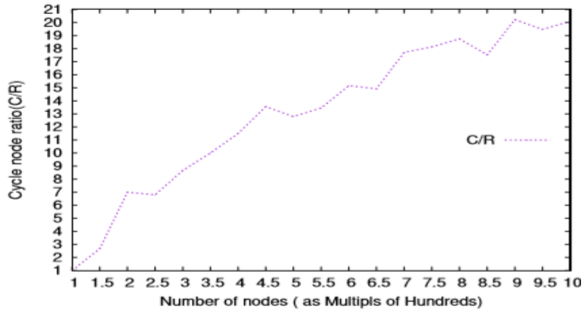

Fig. 1. Number of nodes vs cycle node ratio

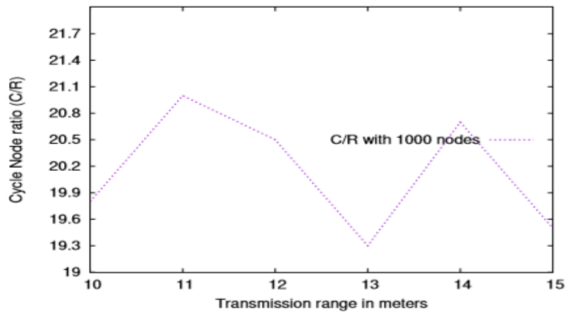

Fig. 2. Transmission range vs cycle node ratio

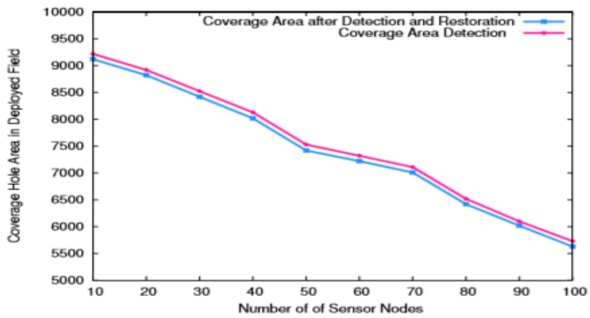

Fig. 3. Coverage hole area after relocating redundant nodes

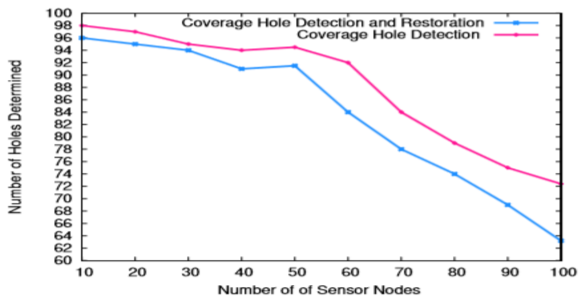

Fig. 4. Number of coverage holes determined versus number of Sensor nodes

Fig. 4 illustrate the total number of coverage hole at each iteration of simulation. Number of coverage holes more during initial phase of sensor node deployment. The number of nodes increased linearly, the number of coverage holes decrease it is due to Gaussian distribution. More number of sensor nodes are placed near the target for surveillance and effective and controllable deployment approach is followed in this paper. The nodes are deployed with target as centre point during simulation Fig. 5 demonstrate the number of recoverable, unrecoverable coverage holes and new set of coverage hole after third iteration. Gaussian distribution is followed for node deployment. The coverage holes are determined based on Hamiltonian cycle, these coverage holes are recovered by relocating the redundant nodes. After relocating redundant nodes, 5% to 8% of the coverage hole are recovered and other coverage holes cannot be recovered. Fig. 5 also illustrate occurrence of the new set of coverage holes.

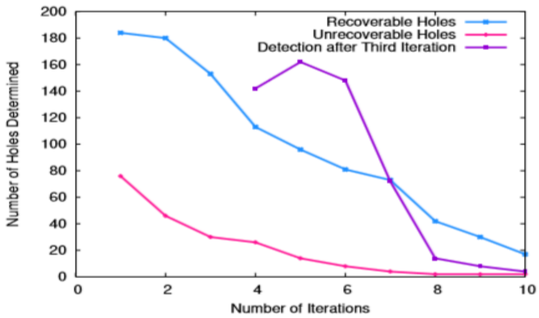

Fig. 5. Coverage holes vs number of iteration.

VI. Conclusions

Coverage of Field of Interest is crucial for surveillance applications; the coverage probability in uniform distribution is controlled by density, sense range and leads coverage holes in the network. In this paper, the Gaussian distribution based penetrating framework is proposed for sensor distribution. To detect coverage holes, Hamiltonian cycle based distributed algorithm have been proposed in this paper. A method to patch these coverage holes in the networks is also proposed. Our simulation results that percentage of coverage holes is small.

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