



Hole and Border Detection Methods and Coverage Enhancement in WSN: A Survey

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Abstract— A wireless sensor network is commonly used to monitoring and recording special events in a geographical area with the help of number of sensors called sensor nodes. These sensor nodes are small in size, weight and portability. They are very vulnerable to various type of failures. These failures forms holes in the coverage area. The four key elements that ensure coverage for WSNs are determining the boundary of RoI, detecting coverage holes and estimating their characteristics, determining the best target locations to relocate mobile nodes to repair holes, and dispatching mobile nodes to the target location while minimizing the moving and messaging cost. The coverage enhancement and hole healing is a big task in the field of wireless sensor networks. There are different methods are available for detecting holes and their boundary. Also different methods are used to enhance coverage area and hole healing. This work goes through the available methods for this purpose and differentiate their performance.

Keywords— Coverage Enhancement, Holes, Hole Detection, Hole Healing, RoI

I. INTRODUCTION

Wireless sensor networks are distributed collection of nodes, where each node has sensing, computation, communication and locomotion capabilities[3]. In recent years, the wireless sensor networks has more importance. There are number of applications present for WSN such as environment monitoring and data collection for various purposes. The sensor nodes are deployed in a region of interest(RoI) either randomly or according to some predefined statistical distribution.

A typical wireless sensor network contain one or more sink or base stations and tens or thousands of sensor nodes. The tiny sensor nodes deployed in the RoI in large numbers and they collaborate to work together to form a network and gather data. The performance of the wireless sensor network depend on these sensors and the coverage of RoI by sensor nodes[2]. However the emergence of holes in the RoI unavoidable because of the inner nature of WSN, sudden deployment, environmental factors, and external attacks. So the area covered by holes or the area devoid of any nodes are not monitored. So the event occurred in this area not reported, therefore the main task of the sensor network is not meet.

The coverage and hole healing functionalities decides the quality of service of a wireless sensor network. It ensure the sensing capabilities of the network. Also it find out the weak points and holes in the network. These information suggest the further effective node deployment. The coverage enhancement decide how to improve the coverage performance when wireless sensor network cannot effectively satisfy application requirements. To guarantee coverage we have to solve coverage problem with sufficient available resources.

The geographical structure of the network or topology is of great importance to both sensor network applications and the implementation of networking functionalities. So the problem of topology discovery, in particular, identifying holes and boundaries in a sensor network is also important. Suppose a large number of sensor nodes are scattered in a region, with neighboring nodes communicating with each other directly. So to find the boundary nodes make use the connectivity information. The boundaries usually have found many applications, such as a constructing floor plan, transportation network, terrain variations, and obstacles (buildings, lakes, etc) [10]. These types of applications shows different design, operational, and management challenges for wireless sensor networks. The challenges are great impact in sensor networks if we consider the constraints of wireless sensor networks such as low computational power and communication bandwidth, limited power of battery, and short communication ranges. Wireless sensor networks differ from ad-hoc networks in several ways. One of the important features is the introduction of the sensing component in sensor networks. A node in a sensor network is thus performing two demanding tasks simultaneously, sensing and communicating. To accomplish these tasks, we normally assume that the node not only performs required sensing of the phenomenon but is also able to communicate with neighbors for onward transmission of the sensed data to sink[1].

The hole detection and border detection in WSN have a tremendous impact on the performance of the WSN. There are different types of holes are present and many types of hole and border detection methods also used to locate holes, border of holes as well as coverage area. The following sections examine the various types of holes present in the WSN and a comparison of methods that are used for hole and border detection. Also examine the coverage enhancement and hole healing in the WSN.

II. DIFFERENTIATE TYPES OF HOLES

WSN contain a sensing component called a sensor or node. So a node can perform sensing and communicate with its neighbors. They are very vulnerable to failures, and can form different types of holes. [1]

- Coverage holes: area not covered by sensing node. This can happen because of obstacle, node failure etc.
- Routing holes: either nodes are not available or the available nodes are can not participate in the actual routing. The main reasons for these holes are, voids in sensor deployment, sensor failure(malfunction), battery depletion, fire or structural collapse.
- Jamming holes: holes made by jammers that are capable of jamming radio frequency.
- Sink/black/worm holes: due to different types of DoS (denial of service).

III. HOLES AND BORDER DETECTION

Various existing methods are used for detecting holes in WSN and border detection. All of them have its own advantages and shortcomings.

In real wireless sensor network the node deployment is not uniform. So these networks contain some regions that are not covered by any sensor nodes, called holes. The TENT rule and BOUNDHOLE [11] are one of the method that used for identifying and build routes around holes. In this method the hole is considered as a region enclosed by a polygonal cycle which contain all the nodes where local minimum can appear. In most of network the communication voids are present due to the local minimum phenomenon in geographical greedy forwarding. In geographical greedy forwarding the source node knows the location of the destination node. A packet is forwarded to the 1-hop neighbor which is closer to the destination. This procedure continue until the destination is reached. A node where a packet is stuck is called the local minimum or stuck node in this process. This local minimum occur due to the presence of hole in the network. The stuck node be one of the boundary node of the hole. To escape packet from stuck node the BOUNDHOLE distributed algorithm is used[11].

The Homology is another method of finding holes and coverage detection in wireless sensor networks. It is a powerful solution to the coverage problem in WSN. In this method two type of communication graphs are used, called rips complex and nerve complex. The nerve communication graph give the details about the coverage intersection about the individual sensor nodes. The rips complex calculate the connectivity information based on the inter node communication. The nerve complex give the accurate information about the coverage but it needs the clear knowledge about the location information of the sensor nodes. This is quite difficult to implement in the practical implementation. The rips complex is an approximation of nerve complex, it is easy to implement and does not need the exact node location. It is a centralized approach so it can have its own algorithmic and topological complexities.

Topological hole and border detection methods are simple distributed approach to locate nodes near the boundary of the sensor field and the hole boundaries. This method purely rely on the topology of the communication graph. Here the only information available is, whether the nodes can communicate with each other or not. The topological methods never use the any location informations about the sensor nodes. The communication graph has node and edges if corresponding wireless station can communicate with each other. If two nodes can communicate with each other then they come under a common communication radius. For proper working of this topological hole and border detection methods a dense communication graph is need.[6,8,10].

IV. AVAILABLE METHODS

In "Coverage and Hole-Detection in Sensor Networks via Homology"[4] the author proposes a hole detection procedure based on homology theory. It make use of two type of communication graph called nerve complex and rip complex. The nerve complex communication graph gives the information about coverage intersection of individual sensor nodes. Its computation is very difficult because the exact location of sensor nodes are needed. The rips complex calculate the connectivity information based on the inter node communication. The homology is an algebraic method for counting holes of various types. There are different types of homologies are present. In this work simple homology with real coefficients. This method studied the problem of detecting topological holes in wireless sensor networks. It uses a distributed scheme that is based on communication topology. A boundary node is detected by comparing its degree with average degree of its 2-hop neighbors. The nodes does not give localization or orientation capabilities. Nodes only give some distance measure of neighbors from strong and weak signal. It is centralized method, therefore it can have centralized computations significant algorithmic and computational complexities. It is not necessary to detect all holes.

The "Blind Swarm for Coverage in 2-D"[5] discuss the coverage problem in robot sensor network. It is a new set of tools for coverage problems in robotic network with minimum knowledge about location and orientation information. This robotic sensor network contain a number of robotic sensor nodes with a unique id which broadcast. All other robots with in this range of can get this broadcast signal as either a strong signal or weak signal based on the distance. This method make use of the homology theory. It only need some minimum amount of environmental knowledge to estimate the coverage. It does not mention any node placement strategy in order to maximize coverage as well as relocation of nodes to fill coverage holes. Also this method depend on some centralized computation with some additional complexities. To detect the strong and weak signal from the broad cast it need for a dual ranged sensing device.

F Stefan in [6] "Topological Hole Detection in Wireless Sensor Networks and its Applications" propose a basic method to detect the inner and outer boundary of holes in wireless sensor networks. It is simple distributed procedure to locate the nodes that come near the boundary of the sensor field as well as near the hole boundaries. This method is

purely based on topology of communication graph. The only information available is which node can communicate with each other. This method does not make use of any location informations of the sensor nodes. So it a simple protocol with only connectivity information required. But its proper working only guaranteed in dense networks. The topology based land mark selection make use of this method.

“Hole Detection or: How Much Geometry How Much Geometry Hides in Connectivity”[7] present an algorithm for detecting hole boundaries in wireless sensor networks that is purely represented by communication graph. If we want to detect the (boundaries of) holes in the monitored space created by fire or other phenomena via examination of the communication graph of the wireless nodes. The communication graph of a wireless network has a node for each wireless station and an edge between two nodes if the respective stations can communicate with each other. For simplicity let us assume that two nodes can communicate with each other if they are within distance of at most 1 (communication radius). So the communication graph is a unit disk graph (UDG). If the communication graph of the network is unit-disk graph determined by geographic location of the sensor nodes then this method correctly identifies the nodes near the hole boundaries. This method is very simple and running time linearly depend on its input.

“Neighborhood-Based Topology Recognition in Sensor Networks”[8] describe the method for determining the structure of boundary nodes of a region. In this work, without use of any location hardware detect boundary, making sensors close to the boundary of the region aware of its position. It also differentiate between exterior boundary and interior boundary, also compute both boundary distance between all nodes and overall region thickness. It also show how communication is possible along the boundary nodes. This method worked on the basic steps like leader election and tree construction. The main drawback of this approach is, the requirement of high density of nodes. To overcome these deficiency, it can exploit higher order information of the neighborhood structure, using sophisticated geometric properties and algorithms [8].

In “A New Approach for Boundary Recognition in Geometric Sensor Networks”[9] describe a new approach with following problem in the wireless sensor networks. A large, dense number of sensor nodes are scattered along a polygonal region R. There is no central control unit, the nodes can locally to neighbor nodes within in the communication radius by make use of wireless radio. There is no information about their coordinate or distance to other nodes. Here build a simple distributed protocol that allow nodes to identify themselves as being located near the boundary of R and form connected pieces of the boundary[9]. It uses the restricted stress centrality to measure topological boundary informations. The distribution of the sensor nodes follow a suitable random distribution is one of the strong assumption of this method. An approach based on random distribution may still fail in sometimes. So this method is more suitable for deterministic methods for boundary recognition.[9]

Y.Wang in [10] proposes another boundary and hole detection method that is based on the topology. Its goal is to find the boundary nodes by make use of only connectivity informations. It does not relay on the node location informations or inter node distance. Its a practical distributed algorithm for boundary detection by using only the communication graph and do not make any unrealistic assumptions. It does not use any location informations, angular informations or distance informations. Also this algorithm is not relay on the unit disk graph model. It is not necessary that the communication graph follow the unit disk graph model. Moreover the algorithms that relay on the unit disk graph sometimes fail in the practical implementation. The holes in the network make changes in the hope count distance, this is the basic assumption behind this method. It identify meaningful boundaries for networks with reasonable node density and distribution. It take only 3 network flooding procedure and well suited for non uniform distribution. The main drawback of this procedure is that. It follow on a centralized approach, so a centralized approach of collecting all of the node information to a central sensor is not feasible for large networks.

“Locating and Bypassing Holes in Sensor Networks” [11] by Qing Fang and Jie Gao propose two algorithms called TENT rule and BOUNDHOLE for identifying the holes in the sensor networks and build routes around holes. According to this method a hole can be defined as a region enclosed by a polygonal cycle which contain all the nodes where local minimum appear. The most sensor networks fail due to the local minimum phenomenon in wireless sensor's greedy forwarding structure. Geographical greedy forwarding is a simple, scalable and efficient method in sensor networks where sensor locations are available. In geographical greedy forwarding, a source node know the location of the sensor node, either by acquiring from location service, or by computing using a hash function in a data centric storage scheme. A packet is forwarded to a one hop neighbor which is closer to the destination. This procedure continue until the packet reach the sink or the packet is stuck at a node if its one hop neighbor far away from destination node. The node where the packet stuck at is called local minimum or stuck node. This method try to focus on defining and discovering holes in the sensor networks as well as building routes around them. It first find out the presence of stuck nodes where the packets possibly get stuck in greedy multi-hop forwarding. The presence of stuck node indicate the presence of holes in the network. To check the presence of stuck node every node in the network execute the TENT rule. To help packets get out of the stuck node the bound-hole method is used [11]. This methods only requires the angle information with in one hop neighbors. It is easier than obtaining accurate location informations.

If a large swarm of immobile sensor nodes that can be scattered in a geographical area such as a street, the nodes does not known any size and shape of environment or position of the nodes. Their only possibility is send or receive message to neighboring nodes with in a communication range. The “Deterministic Boundary Recognition and Topology Extraction for Large Sensor Networks”[12] develop a algorithm and protocol that allow self organization of the scattered sensor nodes. This method works in two stages, in first step it recognize the boundary and in next step topology extraction. One of the key aspect of the location awareness is boundary recognition, making sensors close to the boundary of the surveyed region aware of their position. Once the boundary of the swarm is obtained it can be used to

extract other informations. This approach make few assumptions and produce correct result. But it deals with quite complex combinatorial structures.

“Local Geometric Algorithm for Hole Boundary Detection in sensor networks” [13] introduce a boundary detection algorithm for sensor networks which identifies voids in the networks. It uses fuzzy logic and graph theoretic concepts for computations. This hole detection method is simple and localized. The requirement of synchronization among nodes is one of the drawback of this method. Once the holes and exact boundary of hole is found, by different methods like Robomote[14], iMouse[15] find path trough these voids and communication make possible.

Table I. Comparison Between Proposed Solutions

Proposed solutions	Main drawbacks	Advantages
[4]	Centralized, not necessary to detect a hole	Do not need coordinate and location informations
[5]	Centralized, not mention node placement and relocatin	Minimum assumptions need minimum knowledge about environment
[6]	Centralized, high complexity, work in dense network	Simple, only connectivity informations are needed
[7]	Require high node density	Running time is linear in its inputs
[8]	Assume a uniform node density, require high node density	Computation is easy, distinguish between outside and interior boundaries
[9]	Only for deterministic methods, chance for failure	Distributed method
[10]	Centralized approach, repetitive network flooding	Only 3 network flooding Also implement with non uniform distribution of nodes
[11]	High message density	Distributed, asynchronous
[12]	Require relatively complex combinatorial structures	Distributed, no assumption on the distribution of nodes
[13]	Require synchronization among nodes	Simple and localized

V. COVERAGE ENHANCEMENT AND HOLE HEALING

Monitoring the region of interest (ROI) is the service provided by the wireless sensor network (WSN). The main role of this service is sensing the environment condition and sending the sensed information to the destination node. The ROI must be entirely covered all the time. Holes occur in the ROI cannot be avoided. The occurrence hole is mainly due to nature of WSNs or attacks on WSN network. Hence this affects communication between the nodes. Thus, it is necessary to detect and heal the holes in the network for an effective communication to take place.

Mobile sensor nodes like Robomote, iMouse etc can move around the initial deployment location for maximizing enhancing coverage area. Several movement strategies are make use for this purpose. Because mobile sensors run on batteries, extending their lifetime is an important issue. iMouse thus propose a dispatch problem that addresses how to schedule mobile sensors to visit emergency sites to conserve their energy as much as possible. Integrated mobile surveillance and wireless sensor system (iMouse) consists of numerous static wireless sensors and several more powerful mobile sensors. The static sensors form a WSN to monitor the environment and notify the server of unusual events. Each static sensor comprises a sensing board and a mote for communication. An event occurs when the sensory input is higher or lower than a predefined threshold. Mobile sensors can move to event locations, exchange messages with other sensors, take snapshots of event scenes, and transmit images to the server.[14][15]

One of the key issues in the WSN area is the deployment of mobile sensor nodes in the region of interest (ROI), where interesting events might happen and the corresponding detection mechanism is required. Before a sensor can provide useful data to the system, it must be deployed in a location. Optimum placement of sensors results in the maximum possible utilization of the available sensors. In Energy-Efficient Deployment of Intelligent Mobile Sensor Networks, distributed energy-efficient deployment algorithms for mobile sensors and intelligent devices that form an Ambient Intelligent network are proposed. These algorithms employ a synergistic combination of cluster structuring and a peer-to-peer deployment scheme. In a peer-to-peer mode, each node moves itself to a sparse region so that the coverage of the network may increase and/or an energy-efficient node topology may be achieved. In a clustering mode, each node follows the decision of the cluster-head so that each node spends its energy in a balanced way and performs collaborative missions if necessary.[16]

Distributed sensor networks (DSNs) are important for a number of strategic applications such as coordinated target detection, surveillance, and localization. The coverage provided by a random deployment can be improved using a force-directed algorithm. In DSN, present the virtual force algorithm (VFA) as a sensor deployment strategy to enhance the coverage after an initial random placement of sensors. Sensors do not physically move but a sequence of virtual motion paths is determined for the randomly placed sensors. Once the effective sensor positions are identified, a one-time movement is carried out to redeploy the sensors at these positions. One of the draw back of this method is, it require global computation, ie all the nodes need to run the algorithm.[17]

The movement-assisted sensor deployment deals with moving sensors from an initial unbalanced state to a balanced state. A localized Scan-based Movement-Assisted sensoR deployment method (SMART) develop an optimal load balance solution based on the classic Hungarian method (mesh based) that uses minimum total moving distance. Assume that sensors are deployed randomly into the monitoring area without consideration of any physical obstacles. Then partition the monitoring area into many small regions and use the number of sensors in a region as its load and enhance the coverage of the network by some movement-assisted sensor replacement. It had a drawbacks that, it can cause large message overhead due to the increase of scan. Also it can have global computation and for large number of holes these methods are not sufficient.[18][19]

Self-aware actuation to allow a network to reorganize its available resources and form a new functional topology in the face of run-time dynamics. This approach is called “self aware” because the actuation is not governed by a user command or application but initiated by the network to improve its own performance. In Self Aware Actuation for Fault Repair in Sensor Networks, the performance criterion is coverage, defined as the fraction of the total intended area actually covered by sensor network. This method develop an algorithm referred to as COverage Fidelity maintenance algorithm (Co-Fi) that uses mobility as an adaptive actuation facility for automated deployment repair of the network. This method does not consider the node failure that caused by the physical damage.[20]

Table II. Comparison Between Proposed Solutions

Proposed solution	Main drawback
[17]	Require global computation, ie the algorithm must be run in all nodes
[18]	High message overhead, need more number of network scan,if two adjacent clusters are empty then the scan process will not be correct
[19]	Require global computation, for large holes this method is not efficient
[20]	Require global computation, for large holes this method is not efficient

VI. CONCLUSION

The phenomenon of holes in a wireless sensor network is an interesting factor in many situations, like a disaster detection etc. Sometimes the emergence of hole in the RoI break the communication in the sensor networks. So it is important to detect and recover holes in the wireless sensor networks. Also the QoS of the wireless sensor network decided how we manage the coverage enhancement and hole healing. This work collect the available methods for this purpose and make a comparative study. All of these solutions have its own advantages and bad phases. Most of the existing solutions use global operations to calculate and locate the holes and boundary. Some existing solutions require strong or even unrealistic assumptions. The available methods are evaluating and improving coverage while maintaining connectivity and maximizing the network life time.

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