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Hole Detection and Healing Techniques in WSN

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***Abstract*— One of the major functions of a wireless sensor network is the monitoring of a particular area. Coverage is considered as an important measure of quality of service provided by a wireless sensor network and also emergence of holes in the area of interest is unavoidable due to the nature of WSN nodes. If there is a hole in the network, during data transmission across the hole, the data will move along the hole boundary nodes again and again. This will cause the depletion of energy of nodes in the hole boundary nodes. So detection and healing of such coverage holes is an important factor of concern. There are a number of techniques are introduced to detect and heal holes in WSN. This work reviews these techniques and will explain its merits and demerits.**

***Index Terms*— Coverage, Hole, Hole detection, Hole healing, WSN.**

I. Introduction

A wireless sensor network includes a number of sensor nodes with the capability of communication and computation. Sensor nodes are low power devices equipped with power supply, actuator, processor, memory and radio. In WSN, sensor nodes use radio transmitters and receivers to communicate with each other.
Coverage in wireless sensor network is defined as the ability of sensor nodes to monitor a particular area. Coverage of an entire area means that every single point within the field of interest is within the sensing range of at least one sensor node. WSNs have a lot of applications such as weather forecasting, battle field surveillance, threat identification, health monitoring, environment monitoring, and wild life monitoring. All such interdisciplinary applications that demand random deployment of sensor nodes and uncontrolled external environment may cause holes in the wireless sensor network.
Holes in a wireless sensor network are an area where a group of sensor nodes stops working and does not take part in any computation and communication process. In a wireless sensor network holes are acts as a barrier of communication so that it will affect the performance of the network. During the transmission of data along the hole it will move along the hole boundary nodes repeatedly. This will cause the creation of a large hole due to the premature exhaustion of energy present at the hole boundary nodes. Detection of holes will identify the damaged, attacked and inaccessible nodes in the network. A coverage hole is formed when the sensor nodes are arranged unsystematically in the area.

II. Literature Survey

Approaches for detecting hole in a wireless sensor network can be classified into based on information used, based on computational model and network dynamics. The first category can be again classified as geographical approach which use location information, topological approach which use connectivity information and statistical approach which use mathematical calculations. The second category that is based

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on computational model can be further classified as centralized which use one or two nodes at a centralized location and distributed method in which multiple nodes work together to detect hole. The third category can be classified as techniques which use static sensors and mobile sensors.

A. HDAR

Yang et al. (2010) proposed a hole detection and adaptive geographical routing (HDAR) algorithm to detect holes in wireless sensor networks. It is a geographical approach and hence it use location information of the sensor nodes. In this technique it uses a hole detection ratio to identify the hole. HDAR method will begin its hole detection algorithm when the angle between two adjacent edges of a node is greater than 120 degrees. Here, the ratio of network distance over the Euclidean distance is used as metric to detect a hole, and is called as the hole detection ratio. If there exists a node N such that its hole detection ratio is greater than a predefined threshold value D, then N is considered to be sitting on a hole. One of the main advantages of this approach is that a single node can efficiently detect the hole.

B. Hop based approach

Zeadally et al. (2012) proposed a hop based approach to find holes in sensor networks. There are three phases, namely, information collection phase where each node exchanges information to build a list of x-hop neighbors, path construction phase where communication links between sensor nodes in list of x-hop neighbors are identified, and finally path checking phase where paths are examined to infer boundary and inner nodes. If the communication path of x-hop neighbors of a node is broken, then it is boundary node. Algorithm works for node degree of 7 or higher which is better than some of the other approaches, but there is a huge communication overhead involved in identifying x-hop neighbors.

C. Rips complex method

Martins et al. (2011) used the concepts of Rips complex and Cech complex to discover coverage holes.
Cech complex:- Given a collection of sets U = Ua, Cech complex of U, C(U), is the abstract simplicial complex whose k-simplices correspond to nonempty intersections of k + 1 distinct elements of U.
Rips complex:- Given a set of points X = Xa is a subset of Rn in Euclidean n-space and a fixed radius E, the Rips complex of X, R(X), is the abstract simplicial complex whose k-simplices correspond to unordered (k + 1) tuples of points in X which are pairwise within Euclidean distance E of each other.
After constructing neighbor graph, each node checks whether there exists a Hamiltonian cycle in graph. If not, then node is on the hole boundary. After making decision, each node broadcasts its status to its neighbors. The algorithm further finds cycles bounding holes.

D. DBRA

Kun-Ying et al. (2009) introduced a Distributed Boundary Recognition Algorithm (DBRA) consists of four phases. The first phase of the algorithm will identify Closure nodes (CNs) which enclose the holes and boundary of the sensing field. In the second phase, those closure nodes are connected with each other to form Coarse Boundary Cycles (CBCs) for identifying each obstacle. The third phase is proposed to discover the exact Boundary Nodes (BNs) and connect them to refine the CBCs to be final boundaries. To find the boundary nodes at first, some BNs near the obstacles are selected to initiate the procedure. Some CNs ring-shaped areas are cut off by obstacles, the flooding of packets along these ring-shaped areas must be stopped by the boundaries of obstacles. Hence, the main idea of selecting the initiated BNs is let each CN flood the packets along its two adjacent CNs ring shaped areas and then the nodes on that areas having maximum hop counts will be selected as the initiated BNs.

E. 3MESH-DR

Li et al. (2008) proposed 3MeSH (triangular mesh self-healing hole detection algorithm), which is a distributed coordinate-free hole detection algorithm. It is assumed that each node has uniform sensing radius R and communication radius 2R. Initially a subset of active nodes is selected. An active node x is neighbor of active node y if they are between R and 2R distance apart. Nodes that lie within the sensing range of an active node are called redundant nodes. Connectivity information is collected by each active node from its neighbors. If node detects presence of 3MeSH ring defined by all its neighbors, then it is a boundary node.3MeSH-DR Hole recovery steps

- Active node election

- Broadcasting of neighbor messages
- Comparison of neighbor messages
- Hop count calculation
- Hole detection and recovery

F. Voronoi method

J. Kanno et al. (2009) proposed voronoi method, here voronoi diagrams are used to detect coverage holes. Voronoi diagram is a diagram of boundaries around each sensor such that every point within sensors boundary is closer to that sensor than any other sensor in the network. Voronoi edges in a voronoi cell are the vertical bisectors of the line connecting a particular node to its neighbors. To detect hole, each node checks whether its voronoi polygon is covered by its sensing area. If not, then coverage hole exists. After detecting the hole any of the methods can be used to move the mobile nodes to heal the hole. In vector based algorithm (VEC), sensor nodes are pushed from dense regions to sparse regions so that nodes are evenly distributed. Voronoi based algorithm (VOR) is a pull algorithm which pulls nodes towards sparse regions. In minimax algorithm, target location is at the center of its voronoi polygon.

G. CHDM

Zhao et al. (2011) proposed a coverage hole detection method (CHDM) by mathematical analysis. It is assumed that network consists of mobile nodes each with sensing radius r and communication radius 2r. A node p is defined as neighbor of node q if it lies in its communication range. On the basis of central angle between neighbor sensors, different cases to find coverage holes in communication circle around a redundant movable node are considering here. To patch hole, a redundant node is moved to an appropriate position inside the hole.

H. HEAL

Senouci et al. (2014) proposed HEAL. It is a distributed and localized algorithm for hole detection and healing in which nodes mobility is utilized to recover from the holes. HEAL has mainly two phases.

- Hole Detection
  - Hole Identification
  - Hole Discovery
  - Network Boundary Identification
- Hole Healing
  - HHA Calculation
  - Node Relocation

Hole detection step defined the stuck nodes where packets can possibly get stuck in multi-hop forwarding. A local rule, the TENT rule, for each node in the network to test if it is a stuck node. To identify holes in the network, HEAL proceed in three steps. In the first step it is necessary to assess the existence of a hole, which is done by identifying stuck nodes. Each node in the network executes the TENT rule to check if it is a stuck node. First, it orders all 1-hop neighbors of node p counterclockwise. Let u and v be a pair of angularly adjacent nodes. Second, it draws the perpendicular bisector of up and vp, l1, l2. l1 and l2 intersect at point o and divide the plane into four quadrants. Only the points in the quadrant containing p are closer to p than u and v. Finally, if o is outside the communication range of p, the angle dvpu is a stuck angle and p considers itself stuck node. In the second step all the nodes that are marked as stuck nodes by the TENT rule trigger the discovery of holes. The aim of this step is to find the boundary of the hole and the computation of the holes characteristics. In the third phase the network boundary nodes execute the TENT rule and, as a result, they detect that they are stuck nodes, which will launch the hole discovery and the healing processes even if these nodes are actually not stuck nodes (they are the borders of the network). That is why it is necessary to carry out the network boundary-node identification to avoid that the hole discovery process be launched by those nodes.

Hole healing treats the hole healing with novel concept, hole healing area (HHA). It consists of two sub-tasks, hole healing area determination and node relocation. This allows a local healing where only the nodes located at an appropriate distance from the hole will be involved in the healing process. Determination of HHA will determine the number of nodes that must be relocated to ensure a local repair of the hole. To determine the HHA, here it will estimate the radius of the circle that defines the HHA. After determining HHA, nodes moves towards the hole center.

III. Performance Analysis

A comparative study of the algorithms discussed so far is presented here. The communication overhead, node density and scalability are taken as the parameters for comparison. The performance comparison is summarized in Table I.

TABLE I: COMPARISON OF TECHNIQUES

TECHNIQUE	Communication Overhead	Node Density	Scalability	Mobility
HDAR	LOW	MEDIUM	MEDIUM	NO
HOP BASED METHOD	HIGH	MEDIUM	MEDIUM	NO
RIPS METHOD	HIGH	MEDIUM	MEDIUM	NO
DBRA	HIGH	LOW	MEDIUM	NO
3MESH-DR	HIGH	MEDIUM	HIGH	YES
VORONOI METHOD	LOW	MEDIUM	HIGH	YES
CHDM	LOW	MEDIUM	HIGH	YES
HEAL	LOW	LOW	HIGH	YES

IV. Conclusion

Geometrical approach for hole detection requires GPS enabled sensor and is expensive. They consume a lot of energy and it is not practical for sensors to know their exact location in hostile environment. Topological approach provides realistic results but involves communication overhead. Mobile sensor networks give better coverage. Sensors moved through a long distance will consume more energy. If energy of a sensor is so less that it dies shortly after being relocated to target region, then this effort is wasted. So a combination of geographical technique and mobile sensor nodes will provide large area coverage with low communication overhead and it should consider the energy of the sensor nodes.

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