Hole Detection and Healing for Improving Coverage in WSNs

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Abstract— A Wireless Sensor Network (WSN) consists of a large number of randomly deployed sensor nodes. These sensor nodes arrange themselves into a cooperative network and perform the three basic functions of sensing, computations and communications. Wireless sensor networks (WSNs) are increasingly being used to track objects and monitor various phenomena or region of interest (RoI), where the main task is sensing the environment and communicating this information to the base station. One of the major problems occurring in such environment is the formation of networks holes. Hole is the communication gap. Holes affect the general performance of the networks. In this paper, different hole detection and healing algorithms and methods for increasing the coverage in wireless sensor network is studied.

Keywords*- Wireless sensor network, hole detection, coverage, hole healing*

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I. INTRODUCTION

Wireless sensor network (WSN) consists of a large number of randomly deployed sensor nodes. Sensor node embedded with simple processor, few memory, tiny sensing material, and energy-limited battery. These sensor nodes arrange themselves into a cooperative network and perform the three basic functions of sensing, computations and communications. When the sensors are group together they form a network called sensor network [1].Sensors are quite delicate and vulnerable to various forms of failure, such as battery drain or environmental causes.

Several irregularities can occur in WSNs that impair their functionalities resulting in the formation of different kinds of holes [2], namely: coverage holes, routing holes, jamming holes, and worm holes. There are many reasons for hole formation in the wireless sensor networks. The holes are formed in the Wireless Sensor Networks when a group of sensor nodes are enabled to sense the area around it.

Wireless sensor networks (WSNs) are increasingly being used to track objects and monitor various phenomena or region of interest (RoI), where the main task is sensing the environment and communicating this information to the base station. RoI is completely and continuously covered is very essential. The appearance of holes in the RoI is unavoidable due to the inner nature of WSNs, random deployment, environmental factors, and external attacks. One of the major problems occurring in such environment is the formation of networks holes. Hole is the communication gap. Holes affect the general performance of the networks. Thus, an event occurring within these holes is neither detected nor reported and, therefore, the main task of the network will not be completed.

Different hole detection and healing algorithms and methods for increasing the coverage in wireless sensor network has been studied. The rest of the paper is organized as follows: Section II presents a review of related works on hole detection and hole healing Section III concludes the paper.

II. RELATED WORK

A. Hole and Border Detection

Many related works based on the hole and border detection problem has been done. In [3] authors studied the problem of detecting topological holes in wireless sensor networks with no geographic location information and have a limited communication range. They proposed a novel distributed topological holes detection algorithm which is based purely on the logical communication topology graph. A node makes a decision whether it is on the boundary of a hole by exchanging information with its 1-hop and 2-hop neighbors. Not all the boundaries of holes could be fully described.

The coverage problem is the basic issue in wireless sensor networks. Mohamed K. Watfa and Sesh Commuri in [4] provided a distributed algorithm which discovers the coverage holes in the network and finds those sensor nodes that are on the boundary of coverage holes.

In [5] introduced a novel method for detection and relative localization of sensor network coverage holes in coordinate-free networks assuming availability of a network communication graph. They identify sensor nodes that bound coverage holes by processing information embedded in a communication graph. A hole-equivalent planar graph is created for preserving a number and position of holes. Finally, they build a maximal simplicial complex, which contains the information about coverage holes. The proposed scheme is applicable for both coordinate-available and coordinate-free networks.

Two types of simplicial complexes called Cech complex and Rips complex adopt in [6] to capture coverage holes and classify coverage holes to be triangular and non-triangular. They proposed distributed algorithm with only connectivity information for non-triangular holes detection. This algorithm does not detect triangular coverage holes.

The coverage problem for network which is comprised of mobile sensor nodes with sensing radius r and communication radius R= 2r. In [7] authors presented a coverage hole detection method (CHDM) by mathematic analysis, and then give a node mobility scheme which is engaged to improve the system coverage by moving the redundant node to an appropriate location to cover the detected hole. CHDM can find the hole location more precisely.

Khan, Mokhtar and Merabti in [8] proposed a self detection algorithm in which every node in the network self detects its position, whether it is a boundary node or an inner node by utilizing the information it collects from its neighbors. A node gathers information of its 2-hop neighborhood and properly arranges them in the form of a complete path. The broken path indicates the node is residing on boundary, while in case of closed cycle the node is marked as inner node. The algorithm is efficient in terms of accuracy and energy consumption. In [9] explore sparse sensor networks with lower density, and examine the challenges towards the boundary recognition in sparse networks.

In [10] developed simple and distributed algorithms, the TENT rule and BOUNDHOLE algorithm identify and build routes around holes.

In [11] proposed a distributed boundary node selection algorithms (BNS-Algorithms). BNS algorithms allow B-nodes to self-select based on available 1-hop information extracted from nodes' simple geometrical and statistical features. The efficacy of BNS-algorithms is higher when fewer B-nodes are selected. Accuracy of selection cannot increase because B-nodes do not have the ability to predict their neighbors' status with actual message exchange.

Chu and Ssu in [12] developed a Decentralized Boundary Detection (DBD) algorithm for identifying sensor nodes close to a hole or obstacle in the WSN. The algorithm does not require knowledge of the node locations or distances between two nodes. The proposed algorithm requires only knowledge of three-hop neighboring node information. DBD successfully detects all boundaries in the WSN with the smaller control overhead, and can apply in dynamic networks or new hole occurrence.

Huang, Wu and Zhang in [13] tackle the problem of boundary detection by proposing a simple, distributed and connectivity-based algorithm. The proposed algorithm makes a rough decision on a assumed boundary node by examining its 2-hop iso-contour, and then process the decision based on a heuristic operation, which reduces the size of the assumed boundary node set. The proposed algorithm is applicable in both dense and sparse WSNs.

An improved hole detection algorithm is proposed in [14] based on the Boolean sensing model. The algorithm finds out hole-boundary nodes by Voronoi Diagram and effectively reduces the calculation amount for localization of holes. They adopted Virtual Edge based hole-localization strategy to obtain accurate locations, shapes and areas of coverage holes.

B. Coverage Improvement and Hole Healing

The movement-assisted sensor deployment plans meet coverage and load balance requirements. Fang and Low [15] proposed a unified framework which captures four fundamental attributes that a movement-assisted sensor deployment scheme should have to enhance the coverage of the target field.

An irregular hole results in the redeployment and patrolling tasks inefficiency. A HONOR protocol in [16] regularizes an irregular hole for a mobile WSN and improves the performance of the robot's redeployment and mobile sensors' patrolling tasks.

Wang and Huang in [17] proposed an efficient deployment algorithm proposed to determine the proper position for each of the sensor device in the sensing region and avoided the coverage hole problem and also prolonged the lifetime of the deployed WSN.

In [18] suggested a fuzzy based sensor placement algorithm with the name of FReD. FReD use neighbor's information about location and state to decide on movement

Kao and Lai in [19] presented a multi-hop dynamic moving algorithm to repair the coverage holes. The proposed algorithm takes the density measures into consideration for determining which node to move and to what direction and distance iteratively to heal the holes and also to maximize the overall coverage area.

In the WSN, part of the node failure will affect the normal operation of the whole network. In [20] proposed a self-healing algorithm of cellular-type WSN through improvements of Flooding algorithm based on the frequency of message passing and distance. The algorithm can send the failure information of the node in time and quickly organizes part of nodes into an equilateral triangle mode, which leads to the network self-healing.

A tracking mechanism and a robot repairing mechanism in [21] proposed for maintaining coverage quality of a given WSN. The tracking mechanism leaves robot's footmark on sensors so that they can learn better routes for sending repairing requests to the robot. Repairing algorithm constructs an efficient path that passes through all failure regions and also overcome the unpredicted obstacles.

In [22] proposed a novel scheme to support the redeployment of the sensor network using several mobile robots. This scheme enhances the network connectivity and the coverage ratio of the monitored area.

Hole heal is a method for increasing the coverage ratio, network lifetime, and shorter data transmit time. The proposed algorithm [23] executed on the centre of data receiver, is an analysis of two attributes, including the Holes distance and the Holes size to decide which Holes is critical one to be healed. When a hole-block was selected, a best healing path can be decided

An efficient coverage healing algorithm in [24] always determines an optimal location for each mobile sensor in order to heal all coverage holes, after all mobile sensors locations and coverage holes are located.

In [25] authors developed an adaptive AHCH algorithm to find out the movement schedule for mobile sensors in hybrid wireless sensor networks, such that their relocations can heal the holes, consume minimum moving energy, and maintain the network connectivity all the time.

Delaunay-based coordinate-free mechanism in [26] detect coverage holes and find the locally shortest paths for healing holes in a distributed manner without requiring accurate node location information. DECM incorporates a cooperative movement mechanism that can prevent generating new holes during node movements in healing holes. DECM achieves full coverage more quickly and energy-efficiently and enhance the lifetime of the network. The propose DECM mechanism does not achieve full coverage in a target region with obstacles.

A lightweight and comprehensive a two-phase protocol proposed in [27] called holes detection and healing (HEAL).In this protocol DHD algorithm is used to identify the boundary nodes and discover holes and virtual forces concept relocates only the adequate nodes within the shortest time and at the lowest cost. HEAL provides a cost-effective and an precise solution for hole detection and healing in mobile WSNs. HEAL does not provides on-demand hole detection and healing.

Table1. Hole and Border Detection algorithms

Method/Algorithm used	Description
Topological hole detection algorithm [3]	-The algorithm get information from its 1-hop and 2-hop neighbors and it can determine the boundary of a hole. -Not all the boundaries of holes could be fully described.
Distributed algorithm [4]	-Detects the coverage holes in the region and finds those sensor nodes that are on the boundary of coverage holes.
Partition Network, Locate Holes, TriCollapse algorithm [5]	-Identify sensor nodes that bound coverage holes by processing information embedded in a communication graph.
Distributed coverage hole detection Algorithm [6]	-Detect non triangular holes. -This algorithm does not detect triangular coverage holes.
Coverage hole detection method(CHDM) [7]	-CHDM and a mobility scheme improve sensing coverage
self detection algorithm [8][9]	-Self detects the position of node, whether it is a boundary node or an inner node by utilizing the information it collects from its neighbors
TENT Rule and Bound Hole algorithm [10]	-Identify and build routes around holes.
Boundary node selection(BNS) algorithms [11]	-The efficacy of BNS-algorithms is higher when fewer B-nodes are selected - B-nodes do not have the ability to predict their neighbors' status with actual message exchange.
Decentralized Boundary Detection (DBD) algorithm [12]	- Decentralized Boundary Detection (DBD) algorithm for identifying sensor nodes near a hole or obstacle in the WSN. -The algorithm does not require any information of the node locations or distances between two nodes.
Connectivity-based Boundary Detection Algorithm [13]	-Algorithm makes a rough decision on a assumed boundary node by examining its 2-hop iso-contour, and then process the decision based on a heuristic operation -Applicable in both dense and sparse WSNs.
Nodes Screening algorithm, Hole Localization algorithm [14]	- The Nodes Screening algorithm first screens out boundary nodes using Voronoi Diagram - Virtual Edge based hole-localization strategy is used to obtain accurate locations, shapes and areas of coverage holes

Table2. Coverage Improvement and Hole Healing algorithm

Method/Algorithm used	Description
Virtual force based algorithm[15]	- Achieve a good coverage quality
HONOR protocol [16]	- normalize an irregular hole in a mobile WSN. - efficiently regularizes the hole shape and saves energy consumption and delay time required for the robot's redeployment
Efficient deployment algorithm [17]	- Find out the proper position of each sensor device in the sensing region - prolonged network lifetime and holes problem will be also avoided.
Fuzzy based sensor placement algorithm [18]	-Voronoi diagram is used to detect coverage holes and calculate the target locations of sensors - Fuzzy logic algorithm for controlling the movement of sensors.
Multi-hop dynamic moving algorithm [19]	-Decide which node to move and to what direction and distance to heal the holes -Maximize the overall coverage area
Self-healing Algorithm [20]	- Self healing algorithm can send the failure information of the node, which leads to the network self-healing.
X-correction mechanism, Robot repairing algorithm [21]	-Robot repairing algorithm considers the remaining energy of the robot so that the robot can move back to home for recharging energy and overcome the unpredicted obstacles.
Robots-assisted sensor network redeployment [22]	- Robots to detect and heal connectivity and coverage holes. -Improving the coverage and the connectivity of the monitored area
Holes angle calculation algorithm [23]	- Increase the data throughput and the delivery delay of data transmission.
Coverage hole healing algorithm [24]	- Determine an optimal location for each mobile sensor in order to heal all coverage holes
InAHCH, GenAHCH algorithms [25]	- Handling insufficient mobile sensors as well as disconnected regions
Delaunay-based coordinate-free mechanism (DECM) [26]	-DECM achieves full coverage more quickly and energy efficiently. -DECM can detect coverage holes and find shortest paths for healing holes.
TENT rule, HEAL algorithm, DHD algorithm [27]	- HEAL deals with holes of different forms and sizes -HEAL provides a cost-effective and an exact solution for hole detection and healing in mobile WSNs

III. CONCLUSION

The paper addresses several algorithm literature concerned with hole detection and healing. Holes affect the general performance of the networks. Thus, an event occurring within these holes is neither detected nor reported and, therefore, the main task of the network will not be completed. Today, more and more research is going on related to modified hole detection and healing methods. In this paper literature related to hole detection and healing method is studied.

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