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EBHEAL: Distributed and Localized Mechanism for Coverage Hole Detection and Healing

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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. Here a hole detection and healing technique based on the energy of nodes is described. Energy based EBHEAL has two phases, Hole detection phase and Hole healing phase. Hole detection phase will detect the existence of hole in the network and its characteristics. Hole healing phase make use of these characteristics to heal the hole. Energy of the nodes are considered to improve the efficiency of the hole healing phase.***

Keywords: **Holes, Geographic approach ,Topological approach, Mobile sensors, Static sensors**

1. 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 [1]. 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 [1]. In a wireless sensor network holes act 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. There are different types of holes

- Coverage holes
- Routing holes
- Jamming holes
- Black holes

HEAL is mainly concentrated on coverage holes. A coverage hole is formed when the sensor nodes are arranged unsystematically in the area. It may appear in the network due to energy depletion or poor installment of nodes.

2. Related works

Approaches for detecting hole in a wireless sensor network can be classified into three. Based on information used, based on computational model and based on 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 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. This chapter briefly presents some of such routing protocols.

Yang and Fei [2] 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. This technique 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 the metric to detect a hole, and is called as the hole detection ratio. One of the main advantages of this approach is that a single node can efficiently detect the hole.

Martins et al. [3] 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 pair wise 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.

Martins Kun-Ying Hsieh introduced a Distributed Boundary Recognition Algorithm (DBRA) [4] 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 ex- act 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 CN's 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 CN's ring shaped areas and then the nodes on that areas having maximum hop counts will be selected as the initiated BNs.

Li et al. proposed 3MeSH (triangular mesh self-healing hole detection algorithm) [5], 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 a 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 the presence of 3MeSH ring defined by all its neighbours, then it is a boundary node. For detecting large holes, nodes are allowed to collect connectivity information from nodes further away but at the cost of increased complexity. 3MeSH-DR is an improved version of 3MeSH algorithm which provide detection as well as healing of holes in the network.

This approach [6] 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.

Zhao et al. [7] 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 considered. To patch the hole, a redundant node is moved to an appropriate position inside the hole.

3. Proposed work

In this section a new method Energy based hole detection and healing (EBHEAL) technique is a localized technique to detect and heal holes in a network. EBHEAL has mainly two phases. first phase is hole detection phase and the second one is hole healing phase. In the first phase it will detect existence of holes in the network, its characteristics and the network boundary. In the second phase number of sufficient nodes to heal the hole is calculated. It use a local healing where only the nodes situated at a particular distance from the hole center is used to heal the hole.

3.1 Hole Detection

Hole detection [8] phase includes determining the boundary of the RoI (Region of Interest) and detecting coverage holes and estimating their characteristics.

3.1.1 Hole Identification

Hole identification phase will identify the existence of hole in the region of interest. This phase will access the existence of hole by identifying stuck nodes. Stuck nodes are the nodes in which the packets can possibly get stuck. Stuck nodes are identified by using a local rule called Tent rule. In this rule, for each P, order all of its neighbors counter clockwise. For each adjacent pair (J,H) draw perpendicular bisector of the two edges with P(J, P) (H,P).If these intersect at a point and is out of the communication range of P, then it is called black node. Then it indicates that P cannot be stuck in the direction JPH. By using this rule all the stuck nodes can be identified in the network.

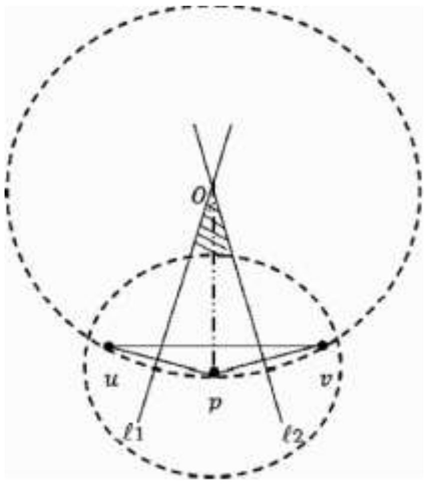

Figure 1: Stuck node identification

3.1.2 Hole Discovery

After detecting the stuck nodes, these nodes will initialize the DHD algorithm. Hole discovery process will specify all the characteristics of the hole like its radius, hole center etc. Each stuck node s_i indicates the hole boundary nodes. Each s_i will generate a Location Information (LI) packet. Each s_i will transmit a LI packet to its neighbor s_{i+1}. In this manner each of the stuck node will collect location information of others. At the end of this process each stuck node will get location information of all other nodes, then it will select two nodes s_m and s_n so that the distance between them is the longest between any two nodes in the set of stuck nodes.

$$Distance(S_m,S_n) = \{Max(S_j,S_k) / S_j,S_k € (s_{0},s_{1,,,,}s_{N})\}$$

In the hole discovery phase then it will calculate the hole centre l from the two stuck nodes S_m and S_n.

$$X_l = (x_{sm} + x_{sn}) / 2$$
$$Y_l = (y_{sm} + y_{sn}) / 2$$

3.1.3 Network Boundary Detection

In the first phase the boundary nodes will also execute the tent rule and identify them as the stuck nodes even though they are not stuck nodes. So it is necessary to distinguish between hole boundary nodes and network boundary nodes. That is why it is necessary to carry out the network boundary node identification to avoid the hole discovery process be launched by those nodes. Network boundary detection phase use information from the previous phase. Detection of network boundary nodes involves the following step

- Each node of the network executes the TENT rule
- Each stuck node launches DHD to identify the nodes that surround the hole
- This phase will compare the x_{max}, y_{max}, y_{min} and x_{min} values with coordinates of each of the stuck node and if it finds that it has a higher or a lower value than one of these values compared to all its neighbours, it sets the corresponding Boolean variable to
- At the end of this procedure, the largest hole that defines the network boundary will be defined by the coordinates x_{max}, $y_{max,}$ y_{min} and $x_{min.}$

3.2 Hole Healing

Hole healing phase includes five subsections, Here node relocation phase use local movement of nodes to heal the hole in the network.

3.2.1 Hole Healing Area Determination

Hole healing area will determine the number of nodes sufficient to heal the hole. Only those nodes will be relocated to heal the hole. This will reduce the overhead due to the node relocation in the network. Here the radius determined in the hole discovery process is used to determine the hole healing area.

$$R = r *(1 + \beta); \beta € R^+$$

where r is the radius of the hole determined in the hole discovery phase. β is a positive constant and it depends upon the sensing radius Rs and density of nodes in the network. Initially algorithm will consider β= 0, i.e radius r is equal to the hole radius. So for the first time it will check whether there is sufficient nodes to heal the hole in the location determined by β= 0.Area defined by the circle when β= 0 is πr^2.Number nodes to be relocated can be calculated as

$$\pi r^2 / \pi R_s^2 = r^2 / R_s^2$$

If these numbers of nodes are not sufficient to heal the hole then it will increment the value.

HEAL is a geographical method which utilizes the mobility of nodes to recover from the holes. Due to the mobility of nodes it provide high scalability and low node density. In wireless sensor networks energy of sensor nodes is an important factor .But in the HEAL method there is no consideration for the energy of the sensor nodes during relocation. If it select a node with lower energy to relocate to heal the hole, it may cause the creation of some other large holes due to the energy depletion of these nodes. Energy consideration while moving the nodes can be considered as a future work of HEAL method. It will assure long network life and efficient resource utilization. Following figure shows the example for this problem.

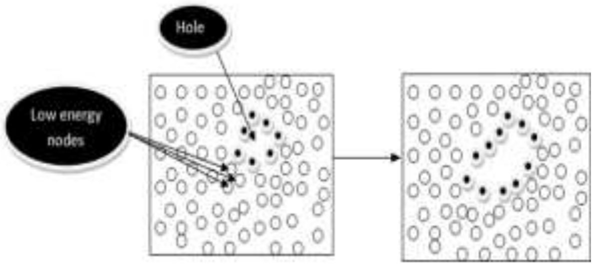

Figure 2: Creation of a large hole

3.2.2 Energy Determination

In this phase energy of nodes will be calculated and is used to determine the nodes that is to be relocated to heal the hole. Each node will collect the energy information of other nodes. Energy of a particular node can be calculated as

$$EL(i) = Residual\ energy(i)=T$$

Here EL(i) is the energy level of node i and T is the minimum energy requirement for a node. Residual energy can be calculated by subtracting consumed energy of a node from its total energy. Nodes with energy less than a particular threshold value will not participate in the node relocation process to heal the hole, otherwise it may cause generation of a new hole in the network.

3.2.3 Advertisement phase

Each node in the hole healing area will give information about its energy value to all other nodes in HHA. In this phase it will calculate a base price value which will be set as zero at the beginning. This information will also be sent to all the nodes in this phase.

3.2.4 Hole healing node discovery

In this phase it will identify the nodes in HHA that have sufficient energy and its base price lower than the hole size. Zero base price of a node indicates that this sensor has not moved yet and most likely it will move to heal some coverage holes soon. so that the generation of a new hole due to the simultaneous movement of sensor nodes can be avoided.

3.2.5 Serving phase

In the serving phase, the mobile sensor chooses the hole with largest size and moves to heal that coverage hole. After movement the hole size will be assigned as the base price of each sensor node.

4. Results and Analysis

Ns2 is a discrete event network simulator. The NS-2 simulation environment offers great flexibility in investigating the characteristics of sensor networks because it already contains flexible models for energy constrained wireless adhoc networks. In this environment a sensor network can be built with many of the same set of protocols and characteristics as those available in the real world. Ns2 is used to simulate large scale experiments not possible in real experiments. Ns2 used to simulate both wired and wireless networks. Nam is a Tcl/TK based animation tool for viewing network simulation traces and real world packet traces. Proposed work is implemented using NS 2.35. In a 1800 x 1200m^2 field, N nodes are randomly distributed. Then Hole is detected and relocates the nodes by exploiting the mobility of nodes.

By evaluating these two systems based on the parameters, the time and the number of nodes in the terms of number of nodes exhausted at a particular time provides the following results. In the case of HEAL number of nodes depleted at a particular time due to the relocation process is higher than that of the EBHEAL. Once the modified version is implemented, introducing the energy determination phase, it is found that the life time of the network is increased. The following graphs (figure 3-5) compare the energy of each node, energy and nod exhaustion of the two systems

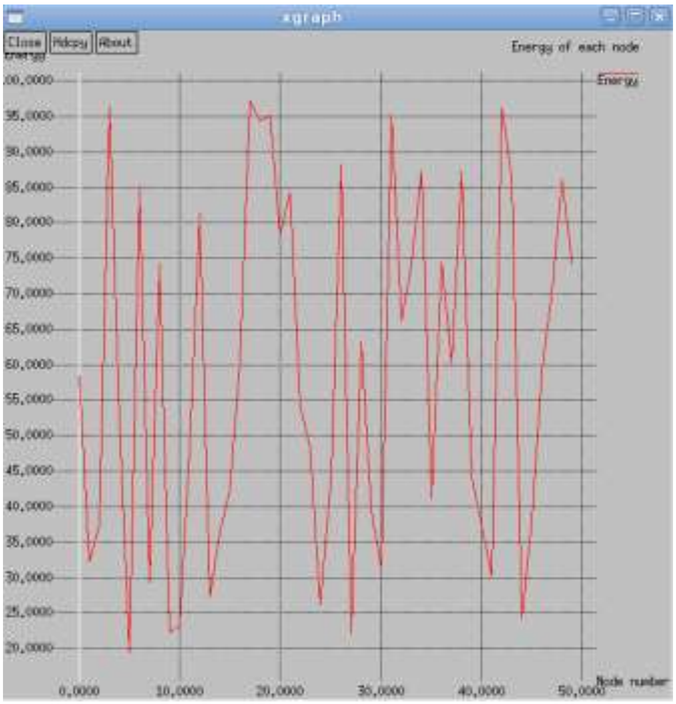

Figure 2: Energy of each node

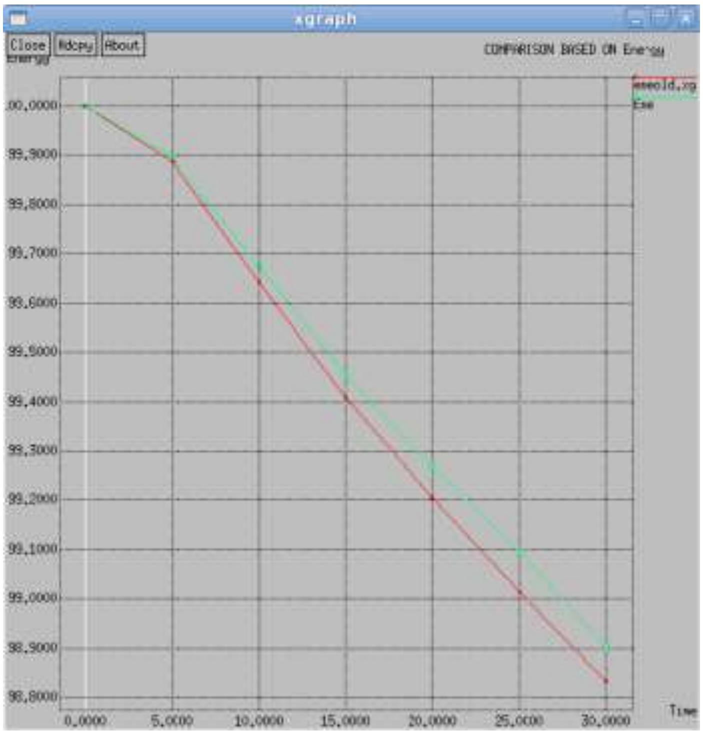

Figure 3: Energy comparison

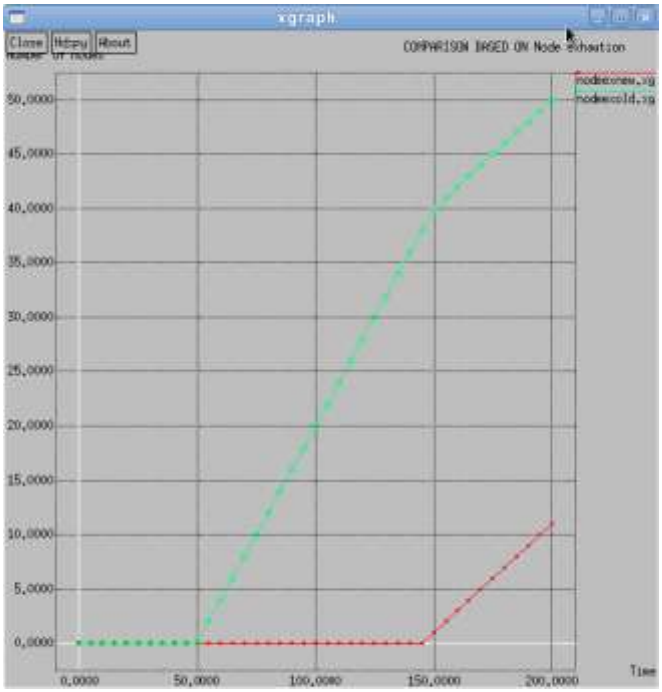

Figure 4: Node exhaustion comparison

5. Conclusion

Denials 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. EBHEAL is a geographical approach with mobile sensor nodes. This method considers energy of the nodes during relocation and hence it can reduce the overhead caused by the relocation process.

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