

An Efficient hole Recovery Method in Wireless Sensor Networks

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Abstract—Sensor nodes are randomly placed in the region of interest. There are hole areas where no sensor nodes exist in some regions. Coverage holes may occur because some nodes run out of energy or physical destruction of sensor nodes. It may reduce the data reliability of the sensor network, and affect the performance of the entire sensor network, such as changing network topology, disconnecting data links, and worsening transmission loads. By discovering the coverage hole in the sensor network and additionally placing new sensor nodes in the detected coverage hole, the coverage hole problem can be solved. Recovery of the coverage hole needs to be designed so that the coverage area is maximized with minimal consumption of sensor resources. In this paper, we propose a method for adding a mobile sensor node at the optimal location by exchanging information between one-hop neighbor border nodes. The proposed method is very intuitive and simple compared to other methods of identifying and restoring coverage holes by structuring nodes in the form of Boron polygons in the sensor network.

Keywords—Coverage holes, Border nodes, Adjacency matrix, Heal node, Isosceles triangle

I. INTRODUCTION

Wireless sensor networks are used to monitor and control the area in a variety of military and civilian sectors, such as battlefield surveillance, intrusion detection, disaster recovery, biological detection, and environmental surveillance. The sensor is randomly placed in the sensing target area to collect environmental data, and the collected data is transmitted to the sink node, which is then processed by the application and provided as a service[1-6].

The coverage hole may occur at an arbitrary position in the sensor network area due to the random arrangement of sensor nodes or the end of the life due to the energy exhaustion of the node. The number and size of these coverage holes gradually may increase over time. Coverage holes reduce the reliability of data and affect the performance of the entire sensor network, including changes in network topology, disconnection of data links, and worsening transmission loads[7-17].

Discovery and recovery of coverage holes is one of the major issues in sensor networks. Coverage holes may be detected by finding the boundary nodes of coverage holes.

DHBND(Coverage Hole and Boundary Nodes Detection)[7] discovers coverage holes by organizing all

sensor nodes in the sensor network into Delaunay triangles. The sensor node recognizes the coordinates of two-hop neighbor nodes based on its location, and constructs a Delaunay triangle based on the distance and the angle information between neighbors. When the circumscribed radius of the Delaunay triangle is larger than the sensing radius of the sensor node, the sensor node recognizes itself as the boundary node of the hole. This method requires a lot of message exchange overhead for constructing a Delaunay triangle and generates errors while a sensor node recognizes the location information of neighbor nodes based on its own location.

In the CGCHD(Computational Geometry based Coverage Hole Detection)[8] method, in order to find a hole boundary node, sensor nodes obtain position coordinate information for two hop neighbor nodes. The two-hop neighbor node group is divided into the upper node set and the lower node set based on the x-axis, and the nodes of each set are sorted based on the x-axis coordinate value. The reference sensor node forms a triangle with two aligned neighbor nodes as vertices. It checks whether the center of the circumscribed circle of the triangle is included in the sensing radius of the other neighboring nodes. In order to determine whether the circumscribed circle center of the triangle is included in the sensing radius of another neighbor node. This method requires a lot of message exchange overhead.

In COVEN(COVERage ENhancing algorithm)[9], sensor nodes are organized in the form of a Boron polygon to restore coverage holes. The sensor nodes recognize that there is a coverage hole when there are non-sensing points in their Boron cell, and restore the hole by placing additional sensor nodes on the line connecting the sensor node and the vertexes of the Boron polygon. This method incurs a lot of message overheads in the process of constructing the entire sensor network as Boron polygons.

The bidding protocol also forms Boron polygons between neighbor nodes. If there is the vertex of the Boron polygon which is farther than the sensing radius, it is determined that there is a coverage hole, and the hole area is repaired by placing an additional sensor node on a straight line connecting the furthest Boron vertex and the sensor node. This method also incurs a lot of overhead in the process of configuring each sensor node in the sensor network as Boron polygons.

Coverage hole recovery should be designed to maximize coverage area with minimal consumption of sensor resources.

In this paper, we propose a NLCHR(Neighbor node Location-based Coverage Hole Recovery) that recovers coverage holes by adding mobile sensor nodes at an optimal location using a minimum amount of resources in exchange of information with neighbor boundary nodes. As the previous study, AMHCD(Adjacent Matrix-based Hole Coverage Discovery)[17] determines the hole boundary node using the adjacency matrix based on the neighbor connection information of sensor nodes. The proposed method adds the mobile sensor node to the optimal location based on the location of two adjacent hole boundary nodes, and reliably recovers the entire coverage hole through an iterative round.

II. PREVIOUS STUDY

Hole discovery technique, AMHCD determines the hole boundary node based on its neighbor node connectivity. If a node is enclosed by the connectivity of one hop neighbor nodes in the closed diagram shape, the node is determined to be an inner node. If the node isn't, it is determined as a hole boundary node. Coverage hole detection consists of hole boundary node discovery and coverage hole identification.

A. Coverage hole boundary node discovery

The sensor nodes collect connection information to two-hop neighbor nodes by using Hello message and generate an adjacent matrix for one-hop neighbor nodes and an adjacent matrix for one-hop and two-hop neighbor nodes based on the information.

Fig. 2a) shows the adjacent matrix for one-hop neighbor nodes of the node 38 in the sensor network of fig. 1. The first row and the first column represent the one-hop neighbor nodes of node 38. Figure 2b) shows the adjacent matrix between one-hop and two-hop neighbor for the node 38, where the first row represents the one-hop neighbor node of the node 38 and the first column represents the two-hop neighbor node of the node 38.

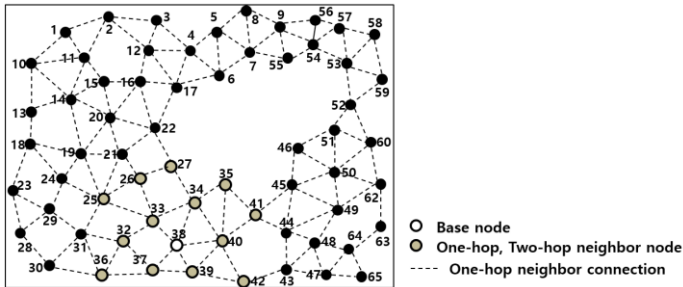


Figure 1. Sensor network model

If the one-hop or two-hop neighbors of a node are connected in a closed diagram, the node is determined to be an internal node, otherwise it is determined to be a hole boundary node.

First, a node with a smallest sum of row elements in the adjacent matrix for one-hop neighbor nodes is selected as a start node of the connection line of neighbor nodes. In fig. 2a),

the sum of the rows of the node 33 and the node 37 nodes are 1 and the sum of the rows of the other nodes are 2. Therefore, one of the node 33 and the node 37 is selected as the start node, and the current node. In the adjacent matrix of one-hop neighbor nodes, the column elements of the current node are examined, and a row with a value of 1 is designated as the next current node. In fig. 2a), the column elements of the node 33 are examined. Since the row of the node 34 is 1, the node 34 is assigned to the next current node.

Examining the column elements of the node 34, the node 33 row and the node 40 row are 1, because the node 33 is already included in the connection line, so the node 40 is designated as the next current node. In this way, the connection line between neighbor nodes is constructed. The connection line between the one-hop neighbor nodes of the node 38 is represented by 33-34-40-39-37.

If the value of the start node column and the end node row in the adjacent matrix for one-hop neighbor nodes is 1, it is confirmed that the start node and the end node have a one-hop relationship with each other. When the start node and the end node are in a one-hop relationship, the reference node is surrounded by a closed diagram by the one-hop neighbor node, and it is determined as an internal node.

If the value of the start node column and the end node row is 0, two hop neighbor connection between the two nodes is checked in the adjacent matrix for one-hop and two-hop neighbor nodes.

In the adjacent matrix for one-hop neighbor nodes in fig. 2a), the value of the start node 33 column and the end node 37 row is 0, it is checked that the two nodes don't have one hop neighbor connection. In fig. 2b), the values of the node 32 row for the node 33 column and the node 37 column are 1, it is confirmed that the start node 33 and the end node 37 have the two-hop neighbor connection. Therefore, the node 38 is determined as an internal node.

If the start node and the end node do not have any connectivity in the adjacent matrices, the reference node is determined to be a hole boundary node.

	33	34	37	39	40
33	0	1	0	0	0
34	1	0	0	0	1
37	0	0	0	1	0
39	0	0	1	0	1
40	0	1	0	1	0

(a) Between one hop neighbor nodes

	33	34	37	39	40
25	1	0	0	0	0
26	1	0	0	0	0
27	0	1	0	0	0
32	1	0	1	0	0
35	0	1	0	0	1
36	0	0	1	0	0
41	0	0	0	0	1
42	0	0	0	1	0

(b) Between one hop and two hop neighbor nodes

Figure 2. The adjacency matrices of node 38

Each sensor node performs a hole boundary node determination algorithm based on their adjacent matrices. The following is the hole boundary node discrimination algorithm based on the adjacent matrices.

$N_c \leftarrow$ A node with a small sum of a row in the adjacent matrix
 For each node i
 // $i = [1:N]$, N : the number of one hop neighbors
 If there is the '1' element in the N_c column of A_{i-1} , $N_c \leftarrow$ the row

End For
 Check connectivity of L_S and L_E
 If the value of the row of L_S and the column of L_E in the A_{1-1} is 1,
 L_S and L_E are connected
 If there is a row in which the columns of L_S and L_E are both 1 in the A_{1-2} ,
 L_S and L_E are connected
 If L_S and L_E have connectivity, N_R is identified as a N_I

TABLE 1. THE NOTATION OF ELEMENTS IN HOLE BOUNDARY NODE DETERMINATION ALGORITHM

N_C	The current node
L_S	The start node of connecting line
L_E	The end node of connecting line
A_{1-1}	Adjacency matrix between one hop neighbor nodes
A_{1-2}	Adjacency matrix between one hop and two hop neighbor nodes
N_R	Reference node
N_I	Internal node
N_B	Boundary node

B. Document Coverage hole identification

Hole boundary nodes forming the same coverage hole have the same coverage hole ID. To get coverage hole ID, the hole boundary node generates an arbitrary number as an initial coverage hole ID, and sends it to the neighboring boundary node by including it in the coverage hole identification message. The coverage hole identification message includes its node ID, coverage hole ID, start node ID, and end node ID. The boundary node that receives the coverage hole identification message from the neighbor boundary node recognizes the same coverage hole if its ID is the same with the start node ID of end node ID included in the message. The coverage hole ID value received from the neighbor boundary node is compared with its own coverage hole ID, and the smaller value is set as its own coverage ID and is transmitted to the neighbor boundary node. When the coverage hole ID value is the same as the coverage hole id value of the coverage hole identification message received from the neighbor boundary node, the transmission of the coverage hole identification message is stopped.

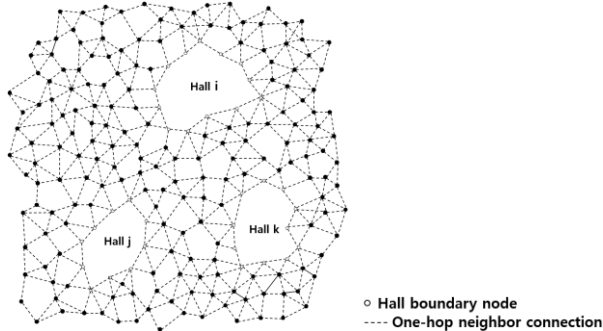


Figure 3. Coverage hole identification

III. NLCHR(NEIGHBOR NODE LOCATION-BASED COVERAGE HALL RECOVERY)

In order to recover the coverage holes, the heal node values of 0 and 1 are alternately assigned to hole boundary nodes while the hole boundary nodes transmit a coverage hole

identification message. The hole boundary node with the heal node value 1 is designated as a heal base node, and the heal base nodes calculate the position of the mobile sensor node to be added to recover the coverage hole.

The coverage hole identification message consists of node ID, hole ID, start node ID, end ID, heal node, and node coordinate fields. The initial boundary node sets the hole ID value to an arbitrary number, sets the heal node value to 0, and transmits a coverage hole identification message including its location. Fig. 4 shows the format of the coverage hole identification message. nID is node ID, hID is hole ID, snID is start node ID, enID is end node ID, HN is heal node value, x is x coordinate of node location, y is y coordinate of node location. It is assumed that the sensor node knows its location.

nID	hID	snID	enID	HN	x	y
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Figure 4. The format of Coverage hole identification message

The hole boundary node which receives the coverage hole identification message recognizes the same coverage hole when the start node ID or end node ID of the received message is its node ID. The node compares its hole ID with the hole ID of the message, and determines the small number as its hole ID.

When a hole boundary node receives a coverage hole identification message with a heal node value 0, it determines its heal node value as 1. When a hole boundary node receives a coverage hole identification message with a heal node value 1, it determines its heal node value as 0. Fig. 5 shows that the hole boundary nodes alternately have heal node values of 0 or 1.

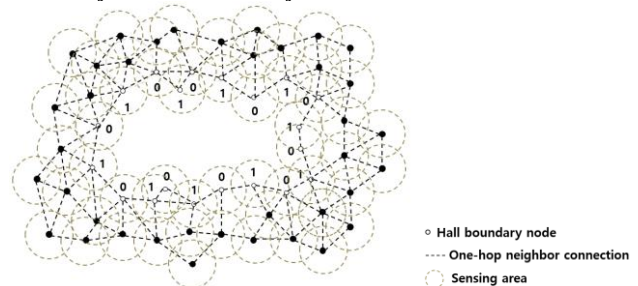
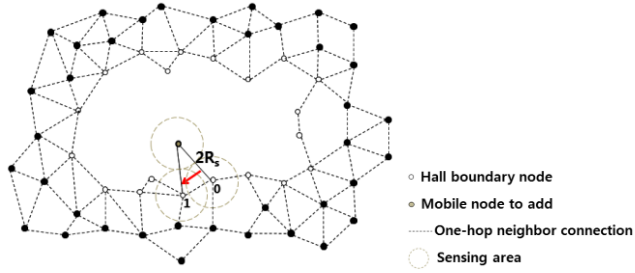


Figure 5. The assignment of heal value of border node

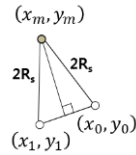
The heal base node calculates the position of the mobile sensor node to add based on the position of the neighbor node included in the coverage hole identification message. The position of the mobile sensor node is a vertex coordinate of an isosceles triangle whose hypotenuse is a double sided sensing radius R_s based on the coordinates of two neighbor hole boundary node.

Fig. 6a) shows a model that calculates the position of the mobile node to add based on the position of the neighbor node after the heal base node receives the coverage hole identification message. Fig. 6b) shows the coordinates of the other vertices of the isosceles triangle, which are determined based on the two coordinates and the length of one face, and

(x_m, y_m) represents the location of the mobile sensor node to add.



(a) Location of mobile nodes in the network



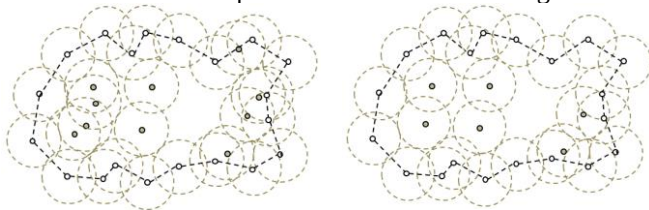
(b) Calculation of coordinate to add

Figure 6. The location of mobile node to add

The heal base node sends a coverage hole recovery request message including the location of the mobile node to advertise the location of the mobile node. The mobile node receiving the coverage hole recovery request message moves to the nearest target location.

In order to solve the problem of redundancy where the mobile sensor nodes are located in the same area, the mobile sensor node that arrives at the hole recovery position transmits a mobile node advertisement message including the current position. If the mobile node receives it from another mobile node less than the sensing radius, the mobile node gives up the role of hole recovery and waits for the next round recovery.

There is a problem of a redundant sensing area with an existing sensor node. To minimize this, the existing sensor node that receives the mobile node advertisement message sends a response message including its location. If there are two or more sensor nodes that are less than their sensing radius, the mobile node gives up the role of coverage hole recovery in that round. Fig. 7a) shows the result that the mobile sensor nodes receive the coverage hole recovery request message and move to the target location. Fig 7b) shows the result that four mobile sensor nodes at overlapping positions giving up coverage hole recovery and only six mobile sensor nodes is placed to recover the coverage hole.

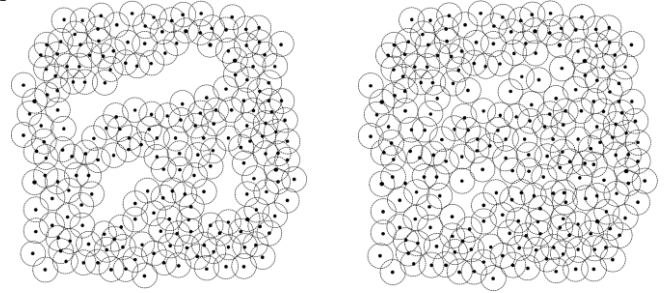


(a) Location of mobile nodes in the network

(b) First round result

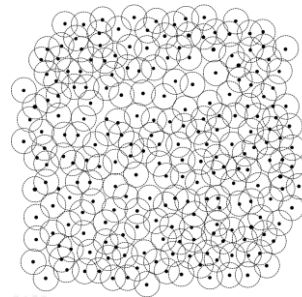
Figure 7. The location of mobile node to add

After the first round coverage hole recovery, the adjacency matrix-based boundary node discrimination is performed, and then the hole recovery of the next level is performed again. The entire coverage hole recovery process is performed until no boundary node is generated in adjacency matrix based boundary node determination. Fig. 8 shows the results of performing coverage hole recovery in each round.



(a) Coverage hall

(b) 1st round coverage hole recovery result



(c) 2nd round coverage hole recovery result

Figure 8. Coverage hall recovery

IV. EXPERIMENT

Experiments were performed to verify the effectiveness of the proposed NLCHR. The experiments were performed where 200 nodes are randomly distributed with the transmission range of 30m, the sensing range of $30/\sqrt{3}$ m in the 200m x 200m area using the C language.

When the sensing range is $1/\sqrt{3}$ of the transmission range, a sensing hole does not occur between one-hop neighbor nodes. Fig. 9a) shows a model in which no sensing holes occur between the neighbor nodes with the maximum transmission distance. R_c represents a transmission radius, and R_s represents a sensing radius. Fig. 9b) shows an isosceles triangle with the transmission radius R_c as the base and the sensing radius R_s as the hypotenuse in the sensing model of fig. 9a).

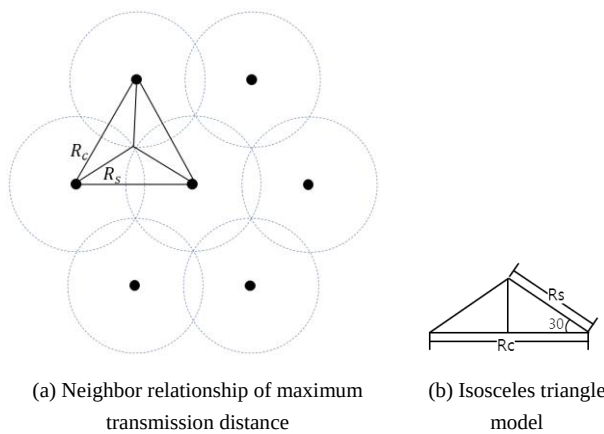


Figure 9. Relationship between communication radius and sensing radius

Equation (1) is the equation generated from the triangle in Fig. 9b). Deriving equation (2) from equation (1), the sensing radius R_s is represented by $1/\sqrt{3}$ product of the transmission radius R_c . When the sensing radius is less than $1/\sqrt{3}$ of the transmission radius, no sensing holes occur between neighbor nodes connected by one hop.

$$\left(\frac{R_c}{2}\right)^2 + (R_s \sin 30^\circ)^2 = R_s^2 \quad (1)$$

$$R_s = \frac{R_c}{\sqrt{3}} \quad (2)$$

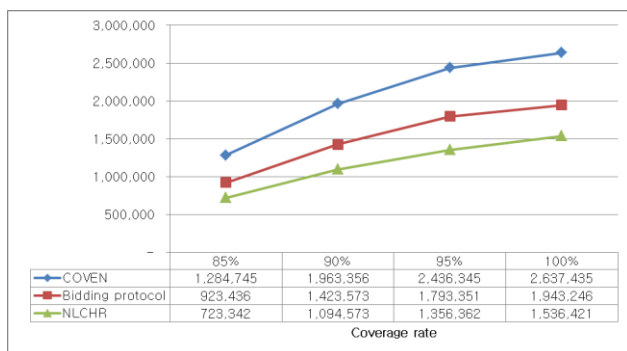


Figure 10. Number of messages

Fig. 10 shows the experimental results for the amount of messages for the proposed method and other coverage recovery methods. The number of mobile nodes used 20% of the number of sensor nodes. The result shows that the greater the coverage rate reached, the greater the amount of messages required. The proposed scheme performs coverage hole recovery with average 56% message transmission compared to COVEN technique, and average 77% message transmission compared to bidding protocol. The proposed technique shows the best performance compared to other traditional coverage recovery techniques.

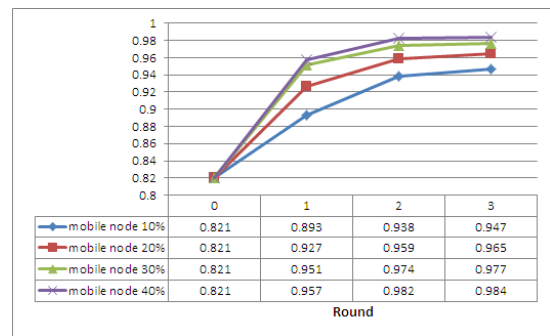


Figure 11. Coverage Recovery Rate

Fig. 11 shows that the coverage recovery rate according to the number of mobile nodes in the proposed method. The result shows that the recovery rate is good as the number of mobiles increases, and the improvement in recovery rate is small when the number of mobiles is 30% and at 40%.

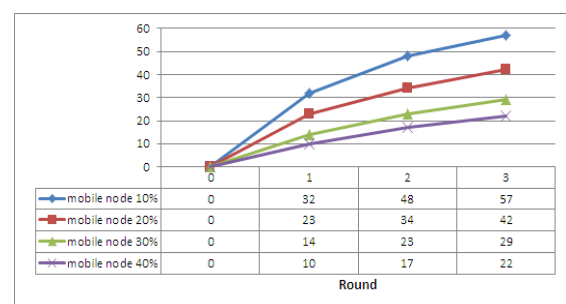


Figure 12. The moving distance of the mobile node

Fig. 12 shows the average moving distance of the mobile node according to the number of mobile nodes in the proposed method. As the round increases, The moving distance of the mobile node is more. This is analyzed as a phenomenon caused by the mobile node of the nearby node recovering the hole in the previous round, and the remaining mobile node moving to recover the coverage hole.

V. CONCLUSIONS

In this paper, we propose an NLCHR method that recovers a coverage hole. Restoration of coverage holes needs to be designed in an efficient way with minimal sensor resources. The proposed coverage hole recovery technique obtains the location mobile sensor nodes to add by exchanging information between coverage hole boundary neighbor nodes, and is very intuitive and simple to apply compared with other methods of identifying and restoring holes by structuring the sensor network in the form of Voronoi diagram or Delaunay triangulation. The proposed method is expected to be easy to apply in the real environment.

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