A Recovery Algorithm to Detect and Repair Coverage Holes in Wireless Sensor Network Systems

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Abstract —Nowadays, wireless sensor network (WSN) systems are widely used in various applications designed to monitor real world physical or environmental phenomena, in more than a few disciplines such as healthcare and habitat monitoring. The position of the sensor nodes significantly affects the accuracy of the information collected, which decides the quality of service offered by the application system. Hence, the deployment strategy is one of the key issues to be solved in WSN. Generally, to reach the end for which the WSN system is designed, full coverage and connectivity must be provided, so each and every event can be detected, and then, guarantee that all the collected information is transmitted to the desired base station for processing and analyzing. When the deployment is not optimally achieved, coverage holes and serious coverage overlapping can occur, which creates uncovered areas and undetected application key events, leading to system mission failure. In this paper, we propose a recovery method based on a gradient algorithm combined with a clustering technique in order to detect the redundant sensor nodes in the whole WSN system and relocates them to heal the identified coverage holes.

Index Terms—WSN, sensor nodes, coverage hole, hole healing, gradient algorithm.

I. INTRODUCTION

Wireless sensor networks (WSNs) play an important role in various civilian and military applications. They are designed for multiple objectives, such as tracking objects (animals, humans, and vehicles), environmental observations (temperature changes, humidity, vibrations, pollution, etc.), habitat monitoring, intrusion detection, and structural monitoring [1], [2]. The objectives of these applications are to first detect the events occurring within a region of interest (ROI) and then transmit all the collected data to the base station (BS) for further processing. Thus, to achieve these goals, each and every point of the ROI must be covered, and each and every node must reach the BS, either directly or via other nodes, so full coverage and connectivity is provided [3].

The most influencing factor in the coverage problem is deployment. The choice of deployment scheme highly depends on the type of sensors, application, and the environment [4]. Deployment is either random or deterministic. On one hand, deterministic deployment is certain to provide high performance, since the node positions are well controlled. It is highly recommended when sensors are expensive and the coverage degree is low or when they must be implemented in some specific location. These circumstances apply to many WSN applications such as seismic monitoring, underwater WSNs, imaging, and video supervising. On the other hand, a random distribution of nodes is the only choice in harsh environments such as a battlefield, a forest or a disaster region. In this case achieving full coverage is always uncertain because of the imprecise location of the nodes, which creates uncovered areas in the ROI, known as coverage holes [5], [6]. To improve coverage, it is recommended to use mobile sensor nodes since they can relocate themselves and design an algorithm for the detection and healing of coverage holes.

In this paper, we demonstrate an approach that identifies the redundant nodes on a network using the Euclidean distance between sensors, then based on the gradient, it relocates them to repair the coverage holes identified on the network. The definitions and coverage holes detection algorithms are presented in Section 2. Then in Section 3 we show all the related work. Section 4 and 5 describe the system model and the problem formulation of the proposed method for detecting and repairing coverage holes, respectively. Finally and before the conclusions, the results are discussed in Section 6.

II. WSN COVERAGE HOLES

Many researchers have studied the discovery and repair of coverage holes. Coverage holes exist, if the required coverage degree is k in a specific application of the WSN and the number of nodes, which covers the region, is less than k during the lifetime of the network [1]. Coverage holes occur often with the random deployment, where the sensor nodes positions are not well controlled, and thus, it is usually uncertain to achieve full coverage, especially when the number of nodes is low [5]. The current work has focused on the repair of coverage holes on the basis of 1-coverage, 1-connectivity. In this case the presence of coverage holes means the existence of uncovered and unconnected areas in the ROI. Therefore, two major issues are faced, undetected events and a failure in the systems connectivity.

Besides coverage hole identification, it is also important to detect coverage overlapping, so redundant nodes monitoring the same area can be relocated during

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the recovery process. However, this operation consumes a lot of energy; thus, to reduce the energy consumption of the network, adjusting the nodes location must be carried out with the minimum number of possible moves, and as indicated in [7], there are four steps to ensure effective coverage in a mobile WSN:

1. Determining the boundary of the ROI
2. Detecting coverage holes
3. Determining the best target location to relocate mobile nodes to repair the coverage holes
4. Minimizing the moving cost when dispatching the mobile nodes to the target locations

According to [6], the coverage hole detection algorithms are classified into different categories: (1) based on the type of information used, (2) based on the computational model, and (3) based on network dynamics.

A. Based on the Type of Information Used

In this category three approaches exist. Firstly the geographical approach, also known as the location-based approach, which assumes beforehand that the location of sensor nodes is known. Secondly, the topological approach, also called the connectivity approach, uses the connectivity information gathered from sensors without knowing there location. Finally, the statistical approach, which assumes that the distribution of nodes follows a statistical function and decides if nodes are at a coverage hole boundary or not.

B. Based on a Computational Model

Algorithms in this category are either centralized or distributed. Centralized algorithms run on one or more nodes found at a centralized location. However, in the case of distributed algorithms, multiple nodes in the network work together to detect the coverage holes. Centralized algorithms consume more energy to achieve a higher percentage of recovered holes when compared to the distributed algorithms. On the other hand, distributed algorithms are more complex than centralized algorithms.

C. Based on Networks Dynamics

In this section coverage hole detection algorithms are divided into (a) static sensors that cannot move after initial deployment unless it is done manually, (b) mobile sensors that can move around after the initial deployment making coverage optimization possible, and (c) finally hybrid sensors that consist of both mobile and static sensors; in this case the coverage holes created by the static sensors can be corrected using the mobile sensors. Mobile sensors permit maximize coverage. However, they affect the topology as they create new connections and break old ones.

III. Related Work

The main objective of solving the coverage problem is to have every location of the ROI within the sensing range of at least one or k sensor nodes depending on the application requirements. Coverage holes are hardly avoided in WSNs due to the various geographical environments of the monitoring region [8]. To solve this problem, a lot of research work has been carried out in this field and the research in this direction is still growing.

Assuming the sensor network to be a hybrid, the authors in [9] developed a distributed protocol to detect coverage holes where the static sensor nodes detect the coverage holes based on the Voronoi diagram and then estimate their size and the target positions, while the mobile nodes relocate themselves to recovery holes. Instead, of using the Voronoi diagram, the authors in [10] demonstrated another approach based on a triangular oriented diagram to detect coverage holes. Using mathematical analysis, the authors in [11] proposed a coverage holes detection method (CHDM) by assuming the network consists of mobile nodes. To find the coverage holes they used the central angle between neighbor sensors and the recovery holes, and the redundant nodes identified and relocated to an appropriate position. A hole detection and healing algorithm (HEAL) was developed in [12] for coverage holes detection and recovery using a virtual forces concept. The authors in [13] detected the coverage holes based on the Voronoi cell structure around each sensor, then estimated the target location using one of the three proposed algorithms: The vector based algorithm (VEC), the Voronoi based algorithm (VOR) or the Minimax algorithm. In [14], a hole detection and adaptive geographical routing (HDAR) algorithm was developed for static network to detect holes using the angle between two adjacent edges of a node and using the ratio of network distance over the Euclidean distance to detect the hole boundary.

All the approaches presented above were developed based on a geographical approach assuming that the location of sensor nodes is already known. Other approaches have been developed based on the topological approach, such as the approach demonstrated in [15], which works with three phases: (a) the information collection phase, (b) the path construction phase, and (c) the path checking phase that detects the boundary hole when the communication path of x-hop neighbors of a node is broken.

To decide if sensor nodes are near a hole or an obstacle, the authors in [16] designed a decentralized boundary detection (DBD) algorithm using a topological approach. By exchanging HELLO messages each node will construct a 2-hop neighbor graph to detect the coverage holes. Then, based on the contour structure, the algorithm identifies the boundary of the network. The authors in [17] proposed an approach that can detect the boundaries of the small holes in the network while reducing the connectivity graph by deleting the vertex and edges. Many researchers have proposed other approaches designed on the basis of topological information, such as Fang, Gao, and Guibas in [18], Bi *et al.* [19], Ghrist and Muhammad [20], Bldg and Funke [21], Li and Hunter [22], Martins, Yan, and Decreusefond [23], and Fekete *et* *al*. [24], to detect coverage holes in static WSNs using connectivity information.

Generally centralized approaches that collect data at a single node suffer from the hardware limitations of the sensors and consume more energy when compared to the distributed algorithms. Based on the network dynamics, hybrid and mobile sensors provide better coverage since they can relocate themselves; however, their energy consumption is high, especially if unneeded moves are made. Finally according to the approaches based on the type of information used, topological approaches provide realistic results but involve a communication overhead, while the statistical approaches achieve optimal performance. However complex statistical calculations are not recommended to be compiled on any sensor node. In the case of the geographical approaches, the main limitation is the need for sensor location using GPS or a scanning device [6]. Each algorithm has its own advantages and limitations, and none is absolutely the best. Some algorithms treat only the coverage hole detection problem, while others present a global solution to the coverage hole detection and recovery problem. Table I concludes the characteristics of the different algorithms in regard of the approach used, the computational model, and network dynamics.

TABLE I: CLASSIFICATION OF COVERAGE HOLES DETECTION ALGORITHMS.

Approach	Researcher (Algorithm)	Computational Model	Network dynamics
Geographical	Wang *et al*. [9]	Distributed	Hybrid
Geographical	Babaie & Pirahesh (HSTT) [10]	Distributed	Hybrid
Geographical	Zhao *et al*. (CHDM) [11]	Distributed	Mobile
Geographical	Senouci, Mellouk & Assnoune (HEAL) [12]	Distributed	Mobile
Geographical	Wang, Cao & La Porta [13]	Distributed	Mobile
Geographical	Yang & Fei (HDAR) [14]	Distributed	Static
Topological	Khan, Zeadally & Jabeur [15]	Distributed	Static
Topological	Chu & Ssu (DBD) [16]	Distributed	Static
Topological	Dong, Liu & Liao [17]	Distributed	Static
Topological	Fang, Gao & Guibas (BOUNDHOLE) [18]	Distributed	Static
Topological	Bi *et al*. [19]	Distributed	Static
Topological	Ghrist & Muhammad [20]	Centralized	Static
Topological	Bldg & Funke [21]	Centralized	Static
Topological	Li & Hunter (3MeSH) [22]	Distributed	Static
Topological	Martins, Yan & Decreusefond [23]	Distributed	Static
Statistical	Fekete *et al*. [24]	Distributed	Static

IV. SYSTEM MODEL

In this paper, we consider a homogenous WSN model where all the sensors are mobile, while a sink node has an unlimited amount of energy and high computational power. The supervised area is considered to be rectangular. We assume that the exact location of the sensors is known and the degree of coverage was equal to one. The node position is denoted as $x_i \in \mathbb{R}^2$ and the sensing range of a sensor is a disk, with Rs being the sensing radius and x_i its center. The communication range is a disk with Rc the communication radius and x_i x_i its center. We consider Rc = 2 × Rs, so coverage implies connectivity. There are two sensor detection models in the WSN to find effective coverage. The binary/ disk sensing model, which assumes that there is no uncertainty, in the contrary the stochastic sensing model that assumes that even within the sensing range of the sensor node there is uncertainty that the event will not be detected. The disk sensing model may not be able to simulate the sensing capability of a real-life sensor accurately because realistic sensors are designed to be small and cheap, and they are unlikely to be sophisticated enough to provide exactly the same detection capability in every direction. The disk sensing model is widely used due to its simplicity and the fact that it enables theoretical abstraction and analysis [3]. In this paper, we use the binary detection model shown in (1); hence, sensors detect all the events within the sensing area.

$$P_d(x_i, x_e) = \begin{Bmatrix} 1 & if & \|x_e - x_i\| \le R_S \\ 0 & if & \|x_e - x_i\| > R_S \end{Bmatrix} \quad (1)$$

where $P_d(x_i, x_e)$ is the detection probability of an event occurring at position x_e and detected within the sensing range of a sensor placed in location x_i. $\|x_e - x_i\|$ is the Euclidian distance between the position of the sensor and the event.

Each point has two characteristics: The coordinates and the interest. The interest is a value that shows the importance given to monitor a point. In Fig. 1, the ROI is presented in a green color, while the white zone presents no importance.

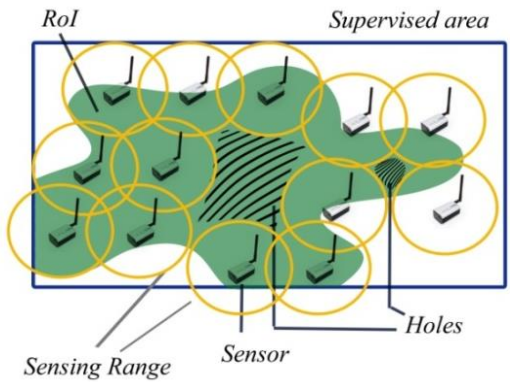


Fig. 1. An example of WSN architecture in the presence of coverage holes.

All points within the ROI are important and need to be supervised, so they will be given an interest Wi equal to 10, however, the interest value of all points within the white zone is zero Each sensor node covers all points of the ROI located within its sensing range, where the Euclidian distance between the node's position and points is less than or equal to Rs. Thus, to rapidly detect these points and to minimize the calculation time, a clustering technique is used. As described in Fig. 2, it consists of selecting a smaller area, a cluster, with the node position as its center and with both sides more than Rs.

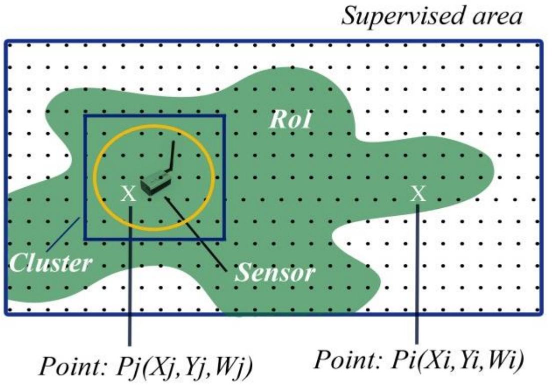


Fig. 2. The clustering technique description.

There is no need to check if the node covers the point *Pi* since it is outside the cluster, only points within its, like *Pj* are to be checked. Besides its position and interest, each and every point will have a third characteristic, which is the sensor node reference Ri that refers to the node monitoring the point. If a point is not covered, the reference value is −1.

V. Problem Formulation

In this section, a coverage hole detection and recovery algorithm has been designed to detect the redundant nodes and coverage holes, which then relocates these nodes to heal the coverage holes using a gradient algorithm. Each center of a cluster is a sensor node position. Let *(Xi,Yi)* be the Cartesian coordinates of a point Pi, and *(Xs,Ys)* the sensor node coordinates. The area of a cluster is defined as follows: $C_k = \{(Xi, Yi) \in R^2 / |Xs\text{-}Xi| \leq R_s \& |Ys\text{-}Yi| \leq R_s\}$

$$C_k = \{(Xi,Yi) \in \mathrm{R}^2 / \quad |Xs - Xi| \leq Rs \quad and \quad |Ys - Yi| \leq Rs\}$$

Based on the Euclidian distance between the sensor nodes, the model identifies any redundant nodes. If the distance between the actual sensor node and its two nearest nodes is less than a threshold, then the actual sensor is considered to be redundant and causes serious coverage overlapping.

$(x_1, x_2, \ldots\ldots, x_i, \ldots x_N) \in \mathbb{R}^2$ is a set of N nodes and x_i denotes the sensor node position. The proposed model uses three functions, the first one $f_D(X)$, given in (2), which allows the detection of redundant nodes using the Euclidean distance between the nodes. The second function $f_S(X)$, given in (3), is the function representing the joint interest of sensor nodes and penalizes coverage overlapping. Finally in (4), $f_G(X)$ is the function that allows the redundant sensors on the hole boundary to move with μ in the right direction to heal the coverage hole using the derivative of the reference function in the direction of $\vec{i}$ and $\vec{j}$.

$$f_D(X) = \delta(X, x^*) / x^* \in X \tag{2}$$

where $\delta(X, x^*)$ is the Euclidean distance between the actual sensor x^* and all the others.

$$f_S(X) = \sum_{i=1}^{N} \alpha_i.area(S_i) - area \bigcap_{i=1}^{N} S_i \tag{3}$$

where α_i is the given importance of location x_i and R_S is the sensing range. $S_i = \{p^* \in Z; \delta(p^*, x_i) \leq R_S\}$ denotes the open ball with center x_i and radius R_s, and $\delta(p^*, x_i) = \|p^* - x_i\|$ is the Euclidean distance between point $p*$ and the actual sensor node x_i x^* and x_i.

$$f_G(X) = \nabla f_{ref}(x, y).\vec{u} \tag{4}$$

where the gradient $\nabla f_{ref} = \langle \partial f_{ref} \partial x, \partial f_{ref} \partial y \rangle$, f_{ref} is the reference function representing the classes of each point on the map, and $\vec{u}$ is the unit vector.

After calculating the Euclidean distance of each sensor to all the others, we sort them in an ascending order. The first minimal distance is always zero since it is between the sensor and itself. In Fig. 3, we demonstrate that if the second and the third minimal distance of the actual sensor with all the others are less than a threshold, which is the sensing range in our case, then there is definitely a redundant node and a coverage overlapping. Thus, the sensor nodes in magenta with the green sensing range are identified as redundant, and will be used during the recovery process.

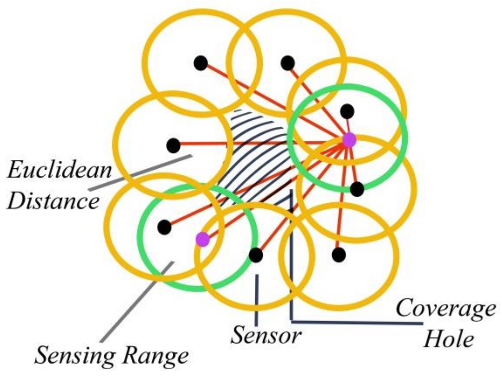


Fig. 3. An example of the redundant nodes in the WSN.

Once the node is redundant, we extract the reference matrix of all the points within a cluster with the node position as its center, then we apply the gradient function in the direction of $\vec{i}$ $\vec{i}$ and $\vec{j}$ $\vec{j}$. If any variations are detected, we localize in that position and we define the direction of movement using the equation of a line. In Fig. 4 we describe how the direction of movement is defined.

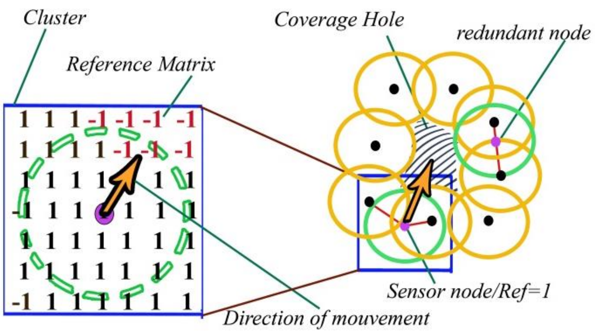


Fig. 4. The description of the direction of movement.

The proposed approach was developed as demonstrated in algorithm 1.

Algorithm 1: Program Code

```
1. X is a set of N nodes(x1…xN).Old_S=0.
2. Sort(X, Ascending order)
//Search for covered points, and redundant
Nodes
3. For i=1:N
  3.1   Define the cluster.
  3.2   Calculate the node's interest Si
  3.3   Calculate the Euclidean distance
        between the actual sensor and all
        others using  fD(X)fD(X).
  3.4   Select the two nearest sensor nodes:
        Minima1, Minima2.
  3.5   If Minima1<=Rs and Minima2<=Rs
     Redundant_Node = [Redundant_Node, xi].
  3.6   End If
4. End for
5. S =fS(X)the collected interest.
6. Old_S=S.

//Calculate the target location, k_max is
the number of iterations needed to relocate
the nodes (e.g.,:k_max=Rc)

7. While (k<k_max)
  7.1   For j=1: length(Redundant_Node)
  7.2   Define the cluster
  7.3   Define target location temp using
         fG(X)fG(X) and its interest S_temp
  7.4   S = fS(X) fS(X)the collected interest.
  7.5   If S> Old_S xi =temp, Old_S=S
  7.6   End If
  7.7   End for
8. End While
9. Display the Map.
```

VI. Results and Discussion

The proposed algorithm was simulated using MATLAB. We considered two scenarios where all the sensors are the same and detect events using the binary model. The sensing range Rs = *12* and the communication range $Rc = 2\times\times Rs$ for both scenarios. The ROI is painted in green and the yellow area has no interest. We define the coverage ratio as the ratio of the covered ROI to the whole ROI and d = 0.2 is the distance used each time to relocate a redundant node.

Scenario 1:

We consider 19 sensors deployed initially over an area of size 80×80 pixels. One coverage hole exists and shown in dark green in Fig. 5. The proposed approach identifies the coverage hole and then based on the gradient algorithm, calculates the target location of each redundant node painted in magenta and relocates them by d, each time until recovering the coverage hole.

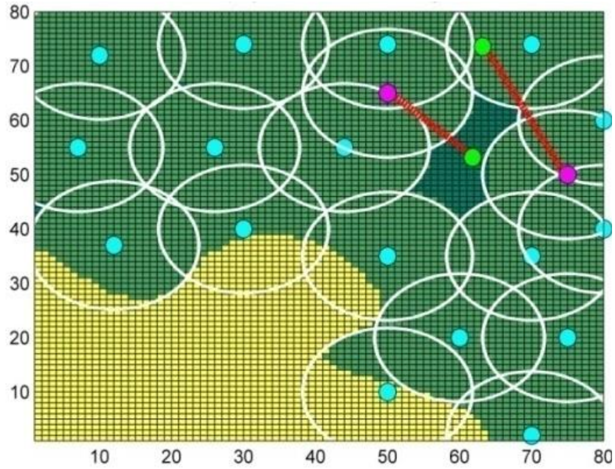


Fig. 5. WSN deployment with 19 sensors and one coverage hole.

The final target location to where a redundant node should arrive is painted in Harlequin in Fig. 5. Fig. 6 shows the final location of the redundant nodes. After several moves the model recovers the coverage hole and the coverage is optimized.

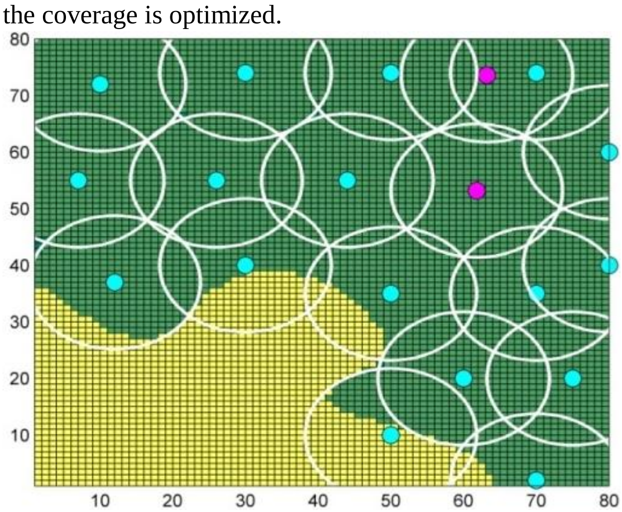


Fig. 6. The WSN architecture after applying the proposed model to detect and heal the coverage hole.

Scenario 2:

In this scenario we presume that 47 sensors are deployed initially over an area of size 140×140 pixels. Two coverage holes exist as shown in dark green in Fig. 7. The proposed method detects the holes and identifies the redundant nodes, then relocates them each time by a small distance *d* in the right direction using the gradient of the reference matrix to heal the nearest coverage hole detected. Fig. 7 shows the initial deployment of the sensor nodes where the coverage overlapping and coverage holes are identified. Fig. 8 demonstrates the final location of the redundant nodes in magenta.

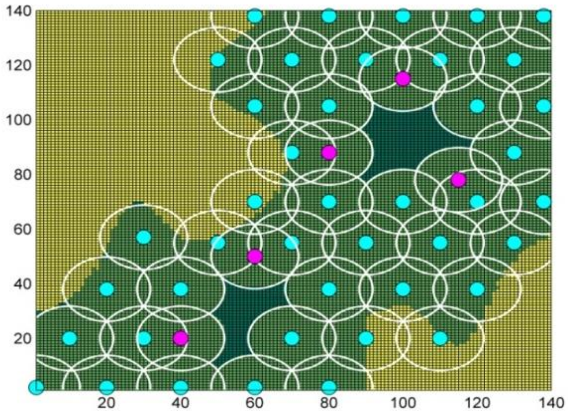


Fig. 7. WSN deployment with 47 sensors and two coverage holes.

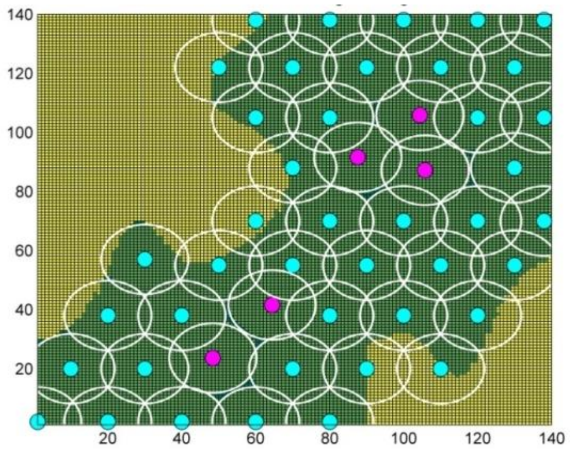


Fig. 8. WSN architecture after applying the proposed model to detect and heal the coverage holes.

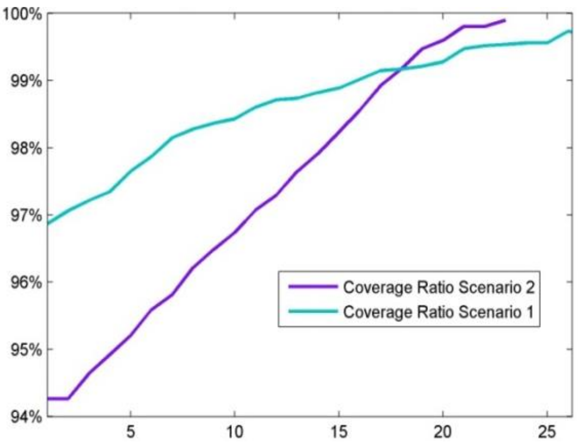


Fig. 9. The coverage ratio for scenarios 1 and 2.

In order to show how the healing process optimizes the coverage, we demonstrate in Fig. 9 the coverage ratio for scenarios 1 and 2. The proposed approach optimizes the coverage from 97% to 99.82% for scenario 1 and from 94.3% to 99.9% for scenario 2. In this section, we tested the proposed algorithm under some precise constraints. Further simulations will be held in the future while comparing our model with other healing algorithms, in order to prove the performance of the proposed approach.

VII. Conclusions

Coverage is considered as an important measure for WSN performance. When coverage holes occur, serious damages must be faced, such as the network failure because of the broken communication links and undetected events because of the uncovered regions in the supervised area. A lot of researchers have considered solving this issue by detecting coverage holes and healing them. Different approaches have been developed based on different WSN application requirements and restrictions. Some approaches use geographical information to detect coverage holes, while others use topological information.

In this paper, we have described some of these approaches and then proposed a geographical-based approach to detect and heal the coverage holes in a WSN. Assuming all the sensors positions are known, the proposed method detects the redundant nodes based on the Euclidean distance between the nodes and heals the coverage holes using the gradient method and by relocating the redundant nodes. In our future work, we plan to prove that our algorithm can be more beneficial. Besides we will focus on how to minimize the sensor movements during the recovery process, in order to extend the networks lifetime.

References

[1] G. Dai, H. Lv, L. Chen, B. Zhou, and P. Xu, "A novel coverage holes discovery algorithm based on voronoi diagram in wireless sensor networks," *International Journal of Hybrid Information Technology*, vol. 9, no. 3, pp. 273-282, 2016.

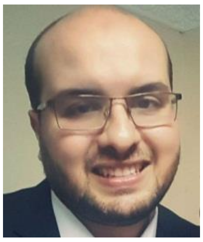
[2] G. S. Rao, "A beneficial analysis of node deployment schemes for wireless sensor networks," *International Journal of Advanced Smart Sensor Network Systems*, vol. 2, no. 2, pp. 33-43, 2012.

[3] Y. Wang, Y. Zhang, J. Liu, and R. Bhandari, "Coverage, connectivity, and deployment in wireless sensor networks," in *Recent Development in Wireless Sensor and Ad-Hoc Networks*, S. Patnaik. 1st ed., Springer, India, 2016.

[4] V. Akbarzadeh, J. Lévesque, C. Gagné, and M. Parizeau, "Efficient sensor placement optimization using gradient descent and probabilistic coverage," *Sensors*, vol. 14, no. 8, pp. 15525-15552, 2014.

[5] P. K. Sahoo, M. Chiang, and S. Wu, "An efficient distributed coverage hole detection protocol for wireless sensor networks," *Sensors*, vol. 16, no. 3, 2016.

[6] P. Antil and A. Malik, “Hole detection for quantifying connectivity in wireless sensor networks: A survey,” *Journal of Computer Networks and Communications*, pp. 1-11, 2014.
[7] R. Kumar and S. Dhingra, “Coverage hole detection in wireless sensor networks,” *International Journal of Computer Networks and Wireless Communications*, vol. 5, no. 4, 2015.
[8] L. H. Zhao, W. Liu, H. Lei, R. Zhang, and Q. Tan, “Detecting boundary nodes and coverage holes in wireless sensor networks,” *Mobile Information Systems*, 2016.
[9] G. Wang, G. Cao, P. Berman, and T. L. Porta. “Bidding protocols for deploying mobile sensors,” *IEEE Transactions on Mobile Computing*, vol. 6, no. 5, pp. 563-576, 2007.
[10] S. Babaie and S. S. Pirahesh, “Hole detection for increasing coverage in wireless sensor network using triangular structure,” *International Journal of Computer Science Issues*, vol. 9, no. 1, pp. 213-218, 2012.
[11] E. Zhao, J. Yao, H. Wang, and Y. Lv, “A coverage hole detection method and improvement scheme in WSNs,” in *Proc. International Conference on Electric Information and Control Engineering*, Beijing, 2011, pp. 985-988.
[12] M. Senouci, A. Mellouk, and K. Assnoune, “Localized movement-assisted sensor deployment algorithm for hole detection and healing,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 25, no. 5, pp. 1267-1277, 2014.
[13] G. Wang, G. Cao, and T. L. Porta, “Movement-assisted sensor deployment,” *IEEE Transactions on Mobile Computing*, vol. 5, no. 6, pp. 640-652, 2006.
[14] J. Yang and Z. Fei, “HDAR: Hole detection and adaptive geographic routing for ad hoc networks,” in *Proc. 19th International Conference on Computer Communications and Networks*, Zurich, Switzerland, 2010, pp. 1-6.
[15] I. Khan, S. Zeadally, and N. Jabeur, “Hop-based approach for holes and boundary detection in wireless sensor networks,” *IET Wireless Sensor Systems*, vol. 2, no. 4, pp. 328-337, 2012.
[16] W. Chu and K. Ssu, “Location-free boundary detection in mobile wireless sensor networks with a distributed approach,” *Computer Networks*, vol. 70, pp. 96-112, 2014.
[17] D. Dong, Y. Liu, and X. Liao, “Fine-grained boundary recognition in wireless ad hoc and sensor networks by topological methods,” in *Proc. 10th ACM International Symposium on Mobile AdHoc Networking and Computing*, New Orleans, LA, USA, 2009, pp. 135-144.
[18] Q. Fang, J. Gao, and L. Guibas, “Locating and bypassing holes in sensor networks,” *Mobile Networks and Applications*, vol. 11, no. 2, pp. 187-200.
[19] K. Bi, K. Tu, N. Gu, and W. Dong, “Topological hole detection in sensor networks with cooperative neighbors,” in *Proc. International Conference on Systems*, Papeete, Tahiti, 2006, pp. 1-5.
[20] R. Ghrist and A. Muhammad, “Coverage and hole-detection in sensor networks via homology,” in *Proc. 4th International Symposium on Information Processing in Sensor Networks*, Los Angeles, USA, 2005, pp. 254-260.
[21] G. Bldg and S. Funke, “Topological hole detection in wireless sensor networks and its applications,” in *Proc. Joint Workshop on Foundations of Mobile Computing*, Cologne, Germany, 2005, pp. 44-53.
[22] X. Li and D. K. Hunter, “Distributed coordinate-free hole recovery,” in *Proc. IEEE International Conference on Communications Workshops*, IEEE, Beijing, China, 2008, pp. 189-194.
[23] P. Martins, F. Yan, and L. Decreusefond, “Connectivity based distributed coverage hole detection in wireless sensor networks,” in *Proc. IEEE Global Telecommunications Conference*, Houston, Texas, USA. 2011, pp. 1-6.
[24] S. Fekete, A. Kroller, D. Pfisterer, S. Fischer, and C. Buschmann, “Neighborhood-based topology recognition in sensor networks,” in *Proc. Algorithmic Aspects of Wireless Sensor Networks*, Turku, Finland, 2004, vol. 3121, pp. 123-136.



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