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Detecting and measuring holes in Wireless Sensor Network

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ABSTRACT

Area detection and measuring is one of the most important problems in Wireless Sensor Network (WSN) because it mainly relates to the continuity and functionality of most routing protocols applied to the Region of Interest (ROI). Electronics failure, random deployment of nodes, software errors or some phenomena such as fire spreading or water flood could lead to wide death of sensor nodes. The damage on ROI can be controlled by detecting and calculating the area of the holes, resulting from the damaged sensor networks. In this paper, a new mathematical algorithm, Wireless sensor Hole Detection algorithm (WHD), is developed to detect and calculate the holes area in ROI where the sensor nodes are spread randomly. WHD is developed for achieving Quality of Service (QoS) in terms of power consumption and average hole detection time. The dynamic behavior of the proposed WHD depends on executing the following steps. Firstly, WHD algorithm cuts down the ROI into many cells using the advantage of the grid construction to physically partition the ROI into many small individual cells. Secondly, WHD algorithm works on each cell individually by allocating the nearest three sensor nodes to each of the cell's coordinates by comparing their positions, WHD connects each cell's coordinate points with the selected sensor nodes by lines which construct a group of triangles, then WHD calculates the area of upcoming triangles. Repeating the previous step on all the cells, WHD can calculate and locate each hole in the ROI. The performance evaluation depends on the NS-2 Simulator as a simulation technique to study and analyze the performance of WHD algorithm. Results show that WHD outperforms, in terms of average energy consumption and average hole discovery time, Path Density algorithm (PD), novel Coverage Hole Discovery Algorithm (VCHDA) and Distriputed Coverage Hole Detection (DCHD).

1. Introduction

Wireless Sensor Network (WSN) is one of the new technologies for detecting and monitoring life phenomenon. WSNs are composed of massive number of sensor nodes operated by small batteries, sensor nodes are mostly deployed in open and unprotected environments. Sensor nodes have significant limitation in communication capabilities and battery power. Nowadays sensor nodes are spread in large scale due to rapid technological advances in micro-electronic industries and the new developed routing protocols which save more communication and computation power (Chen et al., 2017). WSN's can be used in various applications such as target tracking, environmental monitoring, and battlefield surveillance. WSN are composed of hundreds or thousands sensor nodes operated by small batteries, they are spread in open environments to detect and collect information from the surrounded phenomenon (Debnath et al., 2016). Then remote base station receive report messages from the sensor nodes (Zhao et al., Jan 2017). Various applications are dependent on WSNs such as military field exploration, flood of water, border protection and forest fires (Wua et al., 2016; Ahadipour and Haddad, January 2017; Mahapatra et al., 2017).

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WSNs have unique characteristics due to their physical design, such as unreliability of sensor nodes, undefined network topology, high computation and communication power consumption and lots of storage difficulties (Jan et al., 2017; Kadu and Jaini, 2015), So many challenges are presented in the solutions design and applications development of WSNs. In the real life applications, sensor nodes are randomly scattered over the ROI which allow some uncovered areas (Holes) to be present in the ROI, which significantly degrade the network performance. The hole can be defined as the amount of area within the ROI that is not covered by any living sensor. The holes also can be created by the dynamic operations of the sensor nodes. Sensor nodes usually vanished by impact of random deployment, over heat, movement of animals, vehicles and people accidents. Such failures occur due to the static nature and the random deployment of the sensor nodes (Kumar and Dhingra, 2015; Beghdad and Lamraoui, 2016). The failure within any part of the network directly affects the performance of the total network locally and globally. The presence of holes in ROI definitely affect the routing paths, may cause failure of the routing protocols or separation of the network to many individual small networks.

For illustration, the area region that is uncovered by any sensor node is considered as a hole, in which events of interest cannot be accomplished. To overcome the holes problems, the location of the holes and their areas must be determined, also alternative sensors are used respectively to keep the sensor alive as much as possible (Koriem et al., 2016). Therefore, holes coverage and connectivity of the network are from the most important aspects in WSNs (Zaidi and Rakrak, 2016; Antil et al., 2016).

In this paper, a new wireless sensor holes detection algorithm WHD is proposed, which enables the sensor nodes to detect all the holes areas within the ROI, and calculates the holes areas to help the routing protocol to change its routing paths or to put extra mobile nodes to heal the holes areas. The proposed WHD algorithm uses the advantage of dividing the ROI by using the Grid theory (Khan et al., 2015) to divide ROI into many clusters, and it runs in two phases.

- In phase one: WHD divides the ROI into many equally cells by using the Grid algorithm, then it stores the exact location of the four edges of each cell to use them in calculating the holes area.
- In phase two: WHD algorithm works on each single cell individually by determining the coordinates of its four edge points and the coordinates of the nearest three (if possible) nodes to each cell's edge points, then WHD determines if the ranges of the selected sensor nodes cover the cell's edge point, if not means there is a hole and WHD begins to calculate the hole area and its position, yes means that the sensing range of the sensor nodes cover this coordinate point so there is no hole in that region of the cell. Fig. 1 shows how WHD determines the presence of a hole in a cell.

The rest of this paper is organized as follows: Section 2 presents the related work. Section 3 presents the contributions of the research work. Section 4 describes the modeling assumptions and problem goals. The Proposed WHD Algorithm is described in details in Section 5. Section 6 represents the performance evaluation and the simulation results. Section 7 presents conclusion and future work.

2. Related work

Detecting and measuring the holes area is one of the important problems in WSN. So many researchers focused on detecting and calculating the holes areas within the ROI (Kumar and Dhingra, 2015). Authors in (Jewel et al., 2016) propose an algorithm for efficient detection of holes boundary, where each node sends a broadcast message to all its neighbors. If one of the neighbor nodes detects a hole it calculates the distance between itself and the hole, then replays a message to the originator node with the new data. The originator receivers all messages from all nodes and builds the hole boundary region. The drawback of this method, authors use all the available nodes to detect the boundary holes, so the transmitting packets and dropped packets are maximum and the consumption energy due to transmitting and receiving data is very large.

Authors in (Zhao et al., 2016) propose a new algorithm to detect the holes area by forming a boundary region using the available sensor nodes in the region. After formation of the boundary region around the holes, all sensor nodes adjacent to that boundary region is considered as boundary nodes which gives alarm to the routing protocol to avoid this holes region. On the other hand authors don't calculate the holes area and the proposed algorithm uses all the available nodes in the ROI which causes severe power consumption when transmitting data to base station and when calculating the holes boundary. In (Wanand and Zhang, 2016) Extensive research has been dedicated to guaranteeing certain algorithmic performances under less-than-ideal conditions and yet there is certainly more ground to cover. The problem of holes in the network, being it sensing coverage (coverage holes) or topological coverage (routing holes) is still a partially unsolved problem. While there are a plethora of solutions dedicated for holes detection and bypassing, these solutions do not provide an efficient method for continuously monitoring the holes dynamics, such as expansion, merging for healing during run-time.

In (Xu et al., 2015) the authors propose an algorithm based on the sentinel scheme to reduce the sleeping node detection density by defining a new deep sleeping technique. Network life time and power consumption are the factors to calculate the detection rate. Furthermore, the coverage holes is addressed by using a triangular coverage repair procedure to heal the coverage hole.

Authors in (Suku and Philip, 2015) introduce a graphical method to detect the holes region in ROI. They developed an algorithm which divides the ROI into many regions, every region needs at least k number of sensor nodes to construct the boundary area. The proposed algorithm depends on communicating the k number of sensor nodes in circular disc. But authors assume the coverage of a sensor nodes are usually uniform in all directions, furthermore the number of participant sensor nodes to detect the holes region are very large which causes a great power consumption to fulfill the process.

Authors in (Febil and Loganathan, 2016) introduce an algorithm to detect the boundary holes in ROI, the mechanism depends on the connection between each node and three of its neighbor nodes to determine the stuck node, which is the last node to forward the data message. The disadvantages for this method are, the algo-

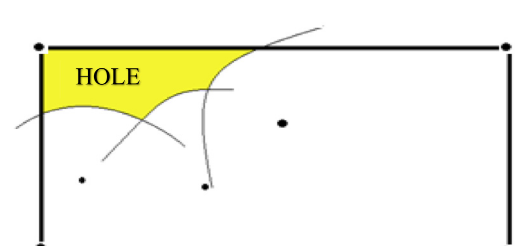

Fig. 1. A hole in one cell.

rithm detects holes of fixed sizes only, the boundary detection is done by comparing one hop neighbor, message forwarding overhead could be very large and the boundary detection is not applicable for large density of nodes. Furthermore the proposed algorithm doesn't calculate the holes area.

Authors in (Prasan et al., 2016) propose an algorithm for detecting the holes boundary in ROI. By detecting the intersection points of the adjacent live nodes the algorithm can draw a figure about present holes area, then the holes area are easily detected by an algebraic method using the intersection points and the sensing ranges of the neighbor nodes to the holes. The proposed algorithm has two weaknesses, firstly it uses all the deployed sensor nodes on the ROI, which causes severe power consumption until the task is accomplished. Secondly the proposed algorithm just defines the boundary region of the holes but doesn't calculate the holes area.

Authors in (Dai et al., 2016) developed an algorithm to calculate the holes area by comparing the size of designed voronoi cell with the adjacent node's sensing range, and marks the border nodes of holes area by using simple geometric calculations. The proposed algorithm assumes that each voronoi cell has sensor nodes and these sensor nodes are able to communicate with each other which causes massive power consumption. Furthermore the proposed algorithm uses all the deployed sensor nodes on ROI to determine just the boundary region not the holes area.

Authors in (Soundarya and Santhi, 2017) developed an algorithm to determine the holes in ROI based on Delaunay Triangulation, authors use the standard geometric tool called Delaunay triangulation to detect the coverage holes. The proposed algorithm depends on direct communication between the deployed sensor nodes together to be able to construct the Delaunay triangulation from the center of these sensor nodes. The proposed algorithm has two weaknesses, firstly the communication overhead is relatively high due to the direct connection between sensor nodes together. Secondly the proposed algorithm doesn't calculate the area of the detected holes but defines the holes region in ROI.

Authors in (Amgoth and Jana, 2017) propose an algorithm which mainly consists of two phases, namely coverage holes detection (CHD) and coverage restoration (CR). In CHD, each sensor node independently detects any hole by updating certain information with its neighbor nodes. To restore the coverage, a sensor node with relatively higher residual energy is given priority to cover the hole closer to it by increasing its sensing range up to a maximum limit. The proposed algorithm has two weaknesses, firstly it depends on direct communication between each two neighbor sensor nodes which leads to a- failing of detecting holes if one sensor has no neighbor node b- communication over head is relatively high due to the direct connection between sensor nodes together. Secondly, the proposed algorithm doesn't calculate the area of the detected holes but defines the holes region in ROI.

Authors in (Yilmaz et al., 2014) aim to design a localization-free and energy efficient hole bypassing technique for fault-tolerant sensor networks. The idea of the proposed algorithm is: firstly, construct a cluster tree rooted at sink node where network is partitioned into multi-hop clusters. Secondly, the authors proposed an inter-cluster energy-efficient solution in the first step and an inter-cluster robust solution in the second step by applying these methods. So the proposed algorithm aims to avoid the cost of localization and network-wide topology recreation. The proposed algorithm has two weaknesses, firstly it depends on all the deployed sensor nodes to determine the holes area which leads to massive communication overhead. Secondly, the proposed algorithm doesn't calculate the area of the detected holes but defines the holes region in ROI.

3. Contributions of the proposed research work

In this section, authors explain how to determine and calculate the total holes area and their breadth formed in the ROI due to random spreading of sensor nodes or damaged sensor nodes by any activities. This study works on enhancing the functions performance of the applied routing protocol on the network. The proposed WHD algorithm studies the ROI for ease of building small cells, which increases the network life time and eliminates the direct communication between the base station and any sensor node.

Therefore, the main contributions of the research work can be illustrated as follows:

- Build a homogeneous ROI for ease and better dealing with randomly scattered sensor nodes as shown in Fig. 2.
- Build WSN reliable model to increase WSN life time by cutting down the ROI into many small pre-defined cells. WHD operates in each single cell individually, then advertise the collected data to base station according to the selected Routing protocol technique as shown in Fig. 3.
- Eliminate the direct communications between the base station and each sensor node, which consumes less power and raises the network lifetime.
- Develop an NS-2 simulator model, describing the performance evaluation of the proposed WHD Algorithm.

4. Modeling assumption and problem goals

4.1. Modeling assumption

In this paper, some assumptions are used regarding the WSNs:

a. Nodes are distributed randomly among a 2-dimentional space e.g. (X, Y).
b. All sensor nodes have the same design, hardware characteristics and have the exact power supply (Battery power).
c. All sensor nodes have the same initial energy power.
d. Radio channel is equal, the amount of energy consumption for message transmission (sending and receiving) is the same.
e. The sensing and the communication ranges are the same for all sensor nodes.
f. Each single node can finds its own position after deployment through GPS devices or other localization approaches.

4.2. Problem goals

WSN is generally considered as an undefined topological environment due to the randomly deployment of static sensor nodes in the ROI, or damage of some sensor nodes due to any activity. So, there is some isolated nodes with no neighboring nodes to connect with. This is why the holes area is created. Our goal is to find the exact estimated amount of holes area in the ROI. Which helps in determining the amount of damaged area in case of natural disasters, support the applied routing protocol to change the routing paths and helps in estimating the position of additional mobile nodes in an appropriate places to heal the holes.

4.3. Definitions

In this section, we define a few terms which are used throughout the paper to develop the proposed WHD algorithm.

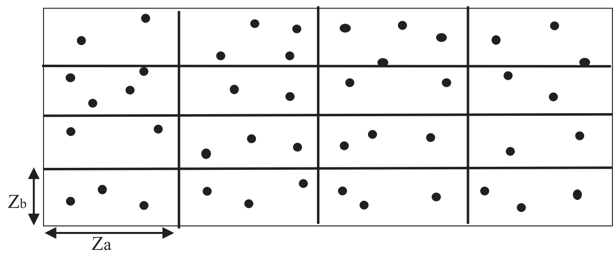

Fig. 2. Formation of Gird.

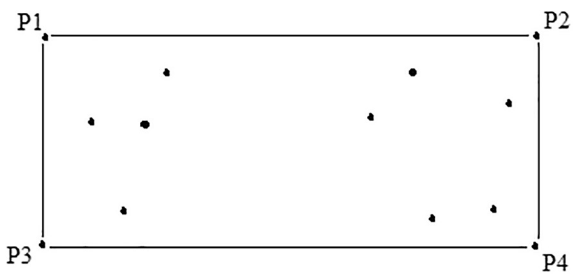

Fig. 3. A single cell.

Let **n** is the number of chosen nodes by the application, $\mathbf{C}_i$ be the number of cells formed on ROI, $\mathbf{P}_i$ is the number of edge points in each cell on ROI, $\mathbf{NH}_i$ is the head node of each cell, $\mathbf{A}_i$ is the area of one formed triangle, $\mathbf{A}_j$ is the area of K + 1 triangles formed at one edge point, $\mathbf{A}_{cell}$ is the total holes area in one cell, $\mathbf{A}_{total}$ is the total holes area in ROI, $\mathbf{X}_0$ is the point which has $\mathbf{x = 0}$, $\mathbf{Y}_0$ is the point which has $\mathbf{y = 0}$, $(X_0, Y_0) = (0, 0)$, **K** is the number of horizontal lines, **m** is the number of vertical lines, $\mathbf{Z_a}$ is the length of the cluster, $\mathbf{Z_b}$ is the width of the cluster.

5. The proposed WHD algorithm

In this section, the WHD algorithm is designed to detect and calculates the holes areas in the ROI. The WHD algorithm works on heterogeneous ROI which has no topology, WHD uses grid algorithm (Khan et al., 2015) to convert the ROI into homogeneous topology then cuts the ROI into many predefined static similar sized cells (According to the area to be served). WHD works on each cell individually, in each cell WHD chooses the nearest (n) number of sensor nodes by comparing the coordinates of the cell's edges points with the position of sensor nodes laying within this cell and chooses the nearest (n) number of sensor nodes. After selecting the nearest (n) nodes within each cell, WHD elects the nearest node to each cell's coordinate as a Head Node (HN) to collect the data from the other nodes and to calculate the holes area by using the triangulation method. WHD is made up of two phases.

- Grid Formation Phase
- Hole Detection Phase

5.1. Grid formation phase

Usually sensor nodes are scattered randomly on the ROI that is the reason of why holes are formed between the adjacent nodes. Also the ROI becomes heterogeneous because there is no defined shape of ROI. So that Grid construction algorithm (Khan et al., 2015) is used to build a homogeneous ROI by building a grid of cells. Each cell is a rectangle of $Z_a \times Z_b$ dimensions. Where Z_a and Z_b are the length and width of the cell.

In this phase the grid formation algorithm is used to divide the ROI into many predefined static similar sized cells, as shown in Fig. 2.

$$\begin{aligned}&\text{For } X = 0 \text{ to } X = k\\&\{\\&\quad \text{For } Y = 0 \text{ to } Y = m\\&\quad \{\\&\qquad f(x,y) = (X_0 + X * Z_a, Y_0 + Y * Z_b)\\&\quad \}\\&\}\end{aligned} \tag{1}$$

5.2. Hole detection phase

This phase is responsible for detecting and calculating the holes area in the ROI. WHD works on each cell individually as shown in Fig. 3. WHD calculates the holes areas by choosing the nearest (n) number of sensor nodes to the coordinates of the cell, the choice is done by comparing the cell's coordinates position with the position of each sensor nodes laying within this cell. After choosing the desired number of sensor nodes WHD elects the nearest sensor node to the cell's coordinate as a Head Node (HN). The HN has two functions, firstly HN collects the data from the other nodes and cascades it according to the selected routing protocol. Secondly HN calculates the holes area by using the triangulation method. Suppose P is a set of edge points of a cell, where P1, P2,..., Pi ∈ P. Then WHD algorithm compares the maximum transmission ranges of the (n) chosen sensor nodes with the position of each cell's edge point, if one of the selected sensor node's transmission ranges hits the grid's edge then there is no hole, If not so definitely there is a hole in that cell, as shown in Fig. 4.

Then WHD calculates the hole area by applying the triangulation method between the chosen sensor nodes and the cell's edge point, by connecting the sensor nodes to the nearest cell's coordinate point which has coordinates (Xn, Yn) with straight lines, then we get (n + 1) triangles created, as shown in Fig. 5.

Depending on triangulation theory we can calculate the hole area in this grid by calculating the area of triangles A1, A2, ... ,An + 1 according to the below formulas, as shown in Fig. 5. Where n is total number of chosen sensor nodes, and r is the radius of the sensor.

$$L_1 = (Y_1 - Y_0 - r) \tag{2}$$

$$L_{n+2} = (X_n - X_0 - r) \tag{3}$$

For I = 1 to n

{

$$L_{(n+1)} = \sqrt{(Y(n) - Y0)^2 + (X(n) - X0)^2} - r \tag{4}$$

$$L_{bn} = \sqrt{L(n+1)^2 - Ln^2} \tag{5}$$

$$\text{Area } A_n = \sqrt{S(S - Ln)(S - L(n+1))(S - Lbn)} \tag{6}$$

$$\text{Where } S = \frac{Ln + L(n+1) + Lbn}{2} \tag{7}$$

$$Lb_{(n+1)} = \sqrt{L(n+1)^2 - L(n+2)^2} \tag{8}$$

$$\text{Area } A_{n+1} = \sqrt{S(S - L(n+1))(S - L(n+2))(S - Lb(n+1))}$$

}

So the area of the hole in one cell (Aj) can be determined by calculating and summing the amount of the individual triangle area by the equation

$$A_j = \sum_{1}^{n+1} Ai \tag{9}$$

where *Ai* is the area of the triangle i that is formed after cutting the hole to many triangles.

By repeating the previous process of calculating the area of holes in one cell to the four edges of the same cell, WHD can discover any holes area in that cell by the equation

$$A_{cell} = \sum_{1}^{4} Aj \tag{10}$$

To calculate the total holes area in ROI, by repeating the previous process on all the cells in ROI, WHD can discover and calculate the total holes area in the ROI. By the equation

$$A_{total} = \sum_{1}^{j} Acell \tag{11}$$

```
The proposed WHD algorithm
Forming Grid on WSN ROI
1-For X = 0 to X = k
2-{
3-   For Y = 0 to Y = m
4-   {
5-      f (x, y) = (X0 + X * Za, Y0 + Y * Zb)
6-   }
7-}
Holes Detection and Calculation
8-For C = 1 to C = i
9-{
10-   For P = 1 to 4 // Find the four edge points for all cells
11-   {
      Find the cell's edge points Pi
12-   }
13-   Do for all the formed cells
14-   {
15-      Find the nearest nodes (n) to cell's edge points
16-      Elect the nearest node to the cell's edge as a Head
    Node (NHi)
17-   }
18-         For each node nj
19-            Do
20-            {
21-               Check if the sensing radius of the sensor ni
    reaches the cell Ci edge's point Pi
22-               If the sensing radius hits Pi
23-               Then there is NO holes in Ci
24-               Else
25-               {
26-                  Draw lines from Pi to each nj and construct
    the triangles
27-               }
28-            }
29-   NHi calculates the K + 1 areas of the hole in this cell Acell
    = ∑_1^{k+1} Ai
30-   Calculate the total area of all cells Atotal = ∑_1^j Acell
31-}
```

6. Performance evaluation

6.1. Simulation parameters

In this section, the performance of the proposed WHD algorithm is evaluated with NS-2 Simulation program against Distributed Coverage Hole Detection (DCHD) (Prasan et al., 2016); Path Density (PD) and novel Coverage Hole Discovery Algorithms (VCHDA) (Dai et al., 2016). For the purpose of comparison and evaluation, the following parameters are taken into consideration:

1. Average energy consumption (i.e. the average energy consumed by the participant sensor nodes to calculate all the holes area in ROI).
2. Average holes discovery time (i.e. the average time duration used by the participant sensor nodes to calculate all the holes area in ROI).

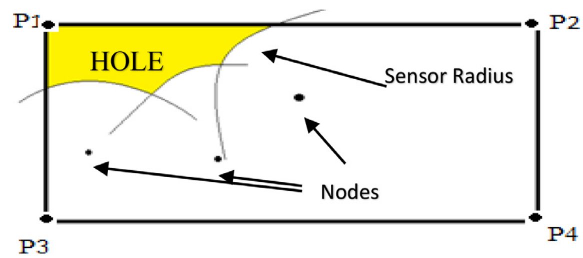

Fig. 4. A hole in a cell.

In the simulation process some standard simulation parameters are used (Dai et al., 2016) for evaluation and accurate comparison between the proposed WHD algorithm and both of VCHDA and PD algorithms. The following table shows the used simulation parameters (See Fig. 6 and Table 1).

6.2. Simulation result

6.2.1. Average energy consumption

Average energy consumption can be defined as the total amount of energy (i.e. computation and communication power) consumed by only the participant sensor nodes, out of the total deployed sensor nodes, during the simulation time. This will continue until the WHD algorithm calculates the total holes area that is found in ROI. Fig. 7 shows the simulation results of the average energy consumption by using all the participant sensor nodes when calculating the holes area in the ROI. This is done by using random number of holes and fixed number of sensor nodes.

As it is known, the amount of energy consumption varies directly with the network density (number of deployed sensor nodes) in the ROI, so as the number of deployed sensor nodes increases, the average energy consumption increases and vice versa. Since the largest amount of consumed energy is mainly caused by communication, WHD uses only a defined number of sensor nodes efficiently to calculate the holes area. Thus the minimal use of sensor nodes leads to many enhancements on the network. Firstly, the minimal communication cost for neighborhood discovery and control information exchange between the base station and any sensor node. Secondly, using minimum number of sensor nodes leads to the minimal amount of aggregated data by the HNs in each cell. Thirdly, by determining the holes area the working routing protocol will avoid that region of holes, which leads to reduce the total network delay.

Fourthly, the dropped packets when communicating between nodes will be minimum so the minimum number of retransmission data between the nodes will be obtained. Accordingly the total number of packets in the network will be the minimum. There is a direct relation between the transmitting packets in the network and the power consumption. So if the transmitting packets, dropped packets, network delay are reduced the average energy consumption decreases.

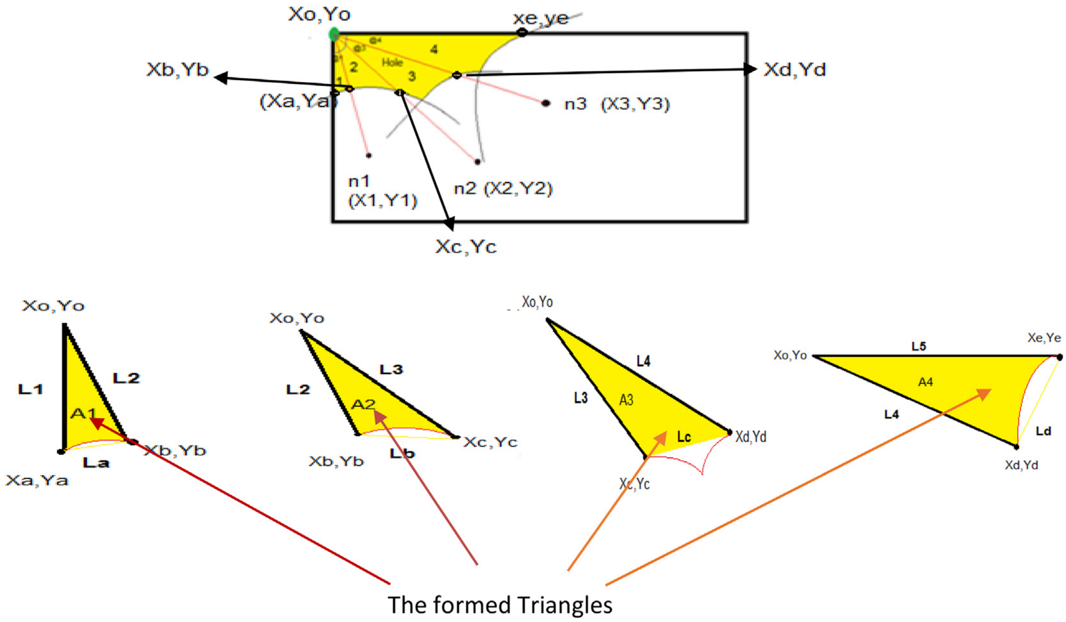

Fig. 5. cutting down the hole into many triangles.

It is clear from Fig. 7 that WHD algorithm outperforms PD algorithm in terms of average energy consumption by approximately 44% average, WHD outperforms VCDHA by approximately 21%, WHD also outperforms DCHD by approximately 15%. The enhancement of average energy consumption is mainly due to the participation of less sensor node. That leads to reduce the communication overhead between the base station and the sensor nodes. Since the WHD algorithm saves more power to calculate the holes area compared to other protocols, WHD enhances the network life time and reduces the communication overhead between the sensor nodes.

6.2.2. Average holes discovery time

Holes Discovery Time can be defined as the total time needed for only participant sensor nodes to detect and calculate the total holes area in the ROI. Fig. 8 shows the simulation results of the average holes discovery time by using only the participant nodes, out of the total deployed sensor nodes, this is done by using random number of holes and fixed number of sensor nodes.

As it is known, the average hole discovery time varies directly with the network density (number of deployed sensor nodes) in the ROI, so as the number of deployed sensor nodes increases the average hole discovery time increases and vice versa. Thus the minimal use of sensor nodes leads to many enhancements on the network. Firstly, using minimum number of sensor nodes leads to the minimal amount of aggregated data by the HNs in each cell. Secondly, the minimal communication and computation effort between nodes Such as neighborhood discovery packets and control information exchange between the base station and any sensor node, this leads to the minimal amount of aggregated data by the HNs in each cell. Thirdly by determining the holes area the working routing protocol will avoid that region of holes, which leads to reduce the total network delay. Accordingly the average holes discovery time decreases.

It is clear from Fig. 8 that WHD algorithm outperforms PD algorithm in terms of average holes discovery time by approximately 46% average, WHD also outperforms VCDHA by approximately 33% average and WHD also outperforms DCHD by approximately 21%, WHD also outperforms DCHD by approximately 21%. The enhancement of average discovery time is mainly due to the participation of less sensor node. That leads to reduce the communication and computation overheads between the base station and the sensor nodes. Since the WHD algorithm saves more power to cal-

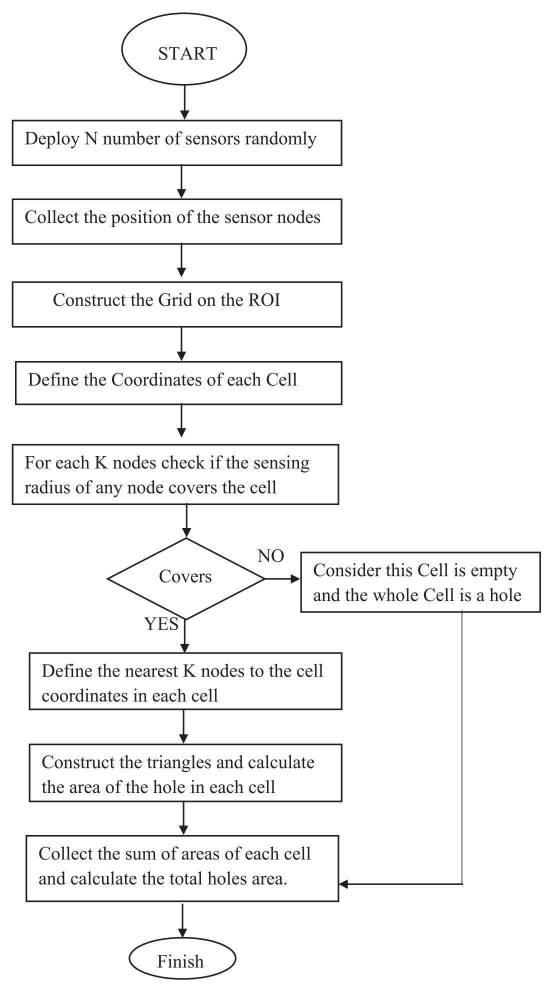

Fig. 6. Flow Chart of WHD.

Table 1
NS-2 Simulation Parameters.

Routing protocol	CRP
Shape of the monitored area	Square
Network size	500 m × 500 m
Number of nodes	100–1500
Base station location	(50, 175)
Data packet size	40 Bytes
Initial energy of nodes	100 J
Communication range	10 m
Data transfer ratio	250 Kbps

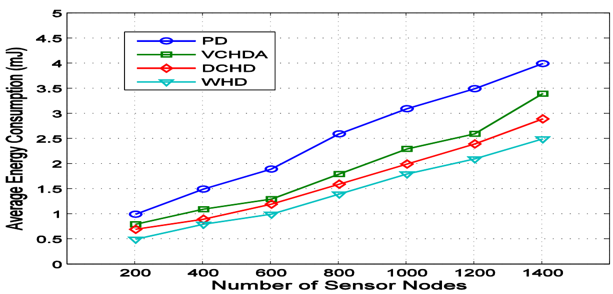

Fig. 7. Average Energy Consumption Comparison.

culate the holes area compared to other protocols, WHD enhances the network life time and reduces the communication overhead between the sensor nodes.

7. Conclusion and future work

Accurate detection and calculation of holes in WSNs do not only help the routing protocols to avoid the detected holes area and modify their routing paths to the destination, but also help in the field of movement tracking such as that of animals, people and vehicles, Also some other phenomena such as fire spreading or water flood.

This paper has presented the WHD (Wireless Hole Detection) algorithm to calculate the total holes area in the wireless sensor networks ROI, where the network nodes operate on limited battery energy. The reduction of the consumed communication time and computational power is considered the main challenge regarding this network. The WHD offers the advantage of small transmission distances for most of the sensor nodes. This concept leads to increasing the network lifetime and decreasing the communication and computation overheads as well as enhancing the quality of the network.

The basic concept of the WHD is as follows.

- WHD divides the WSN into a number of similar cells by using the grid algorithm.

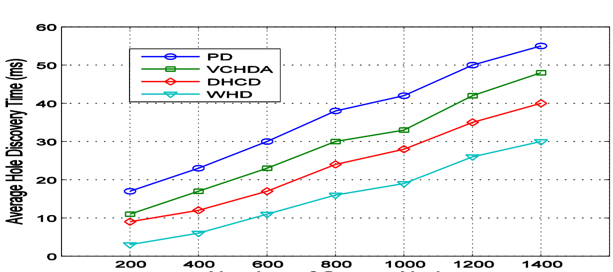

Fig. 8. Average Hole Discovery Time Comparison.

- WHD works on each cell individually by storing each cell's coordinate positions and finds the nearest number of sensor nodes (depending on the application) to each coordinate.
- WHD begins to cut each cell into a number of triangles by drawing lines between each coordinate and the selected number of sensor nodes.
- WHD algorithm calculates the area of the formed triangles in each cell which represents the holes area in that cell.
- WHD sums the total holes areas in every cell to calculate the total holes area in the ROI.

Since the energy consumption is mainly caused by communication, so less sensor nodes are used to calculate the holes area. This leads to the minimal communication cost for neighborhood discovery and control information exchange between base station node and the sensor nodes. Also the amount of aggregated data by the HN are minimal due to the minimal use of sensor nodes in each cell. For the above achievements the average energy consumption, communication overhead and average holes discovery time decreases. Subsequently the network life time increases accordingly.

In order to evaluate the performance of the proposed WHD algorithm, we compare its performance results with those obtained from PD and VCHDA algorithms in terms of average energy consumption and average holes discovery time. Based on these comparisons, it is obvious that the upcoming results are more efficient and increase the network life time in favor of WHD algorithm. In our future work, we shall try to recover these holes with less number of mobile nodes.

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