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A novel approach for detection of coverage holes in Wireless Sensor Networks

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Abstract— Wireless sensor network consists of low powered battery operated tiny sensor nodes that are designed to work independently. Coverage is a prominent issue in WSNs that affects the quality of service. Coverage holes can appear anywhere in the monitored region because of several reasons like energy depletion, link failure etc. In this paper, a decentralized, node based, localized coverage hole detection algorithm is proposed. It works in two phases. In the first phase, each node identifies the critical boundary points with its neighbors. Thereafter in second phase, all critical points will be grouped together to form a hole. Simulation results show that our algorithm works better than existing detection algorithm.

Keywords— Wireless Sensor Networks, Critical Boundary Points, Coverage Holes, Detection of Coverage Holes.

I. Introduction

Wireless Sensor Networks are comprised of tiny sensing nodes equipped with limited battery power. These nodes are designed to provide specific services for applications like weather forecasting, surveillance systems, military applications etc. [1]. Sensing nodes deployment can be random or manual according to application requirement. These nodes collect or sense the data then process and send to the base station. Some critical security applications like intrusion detection and battlefield monitoring need fully covered target area to deliver its services efficiently. After some rounds of communication, some sensing nodes get exhausted because of energy depletion that may result some part of area to be uncovered by sensors. That uncovered area is called coverage hole and this problem is called coverage hole problem [2, 3]. These uncovered areas severely affect the performance of network. Therefore, there is a need of an approach for accurate detection of those areas.

Some coverage preservation algorithms are proposed in [2-5] to enhance the coverage lifetime of network. Algorithms proposed in [2, 3] are coverage based scheduling algorithms intend to increase coverage lifetime by balancing energy consumption of network. Some clustering algorithms proposed in [4, 5] are based on both coverage and energy parameters. In these algorithms a sensor node with hundred percent overlapped area will be selected to route the data. But after some transmission rounds problem of inescapable coverage holes will occur surely. Algorithms in [6-8] are also for coverage preservation but they do not have any detection technique for uncovered regions. Some other techniques for detection of coverage holes are proposed in [9-11] but they are also containing many lacks.

In this paper, we are mainly focusing on to propose a new algorithm to detect uncovered area in network. Our proposed algorithm is using crucial boundary points of sensing nodes to detect exact location and size of coverage hole.

Rest of our paper is organized as: section II is a detailed literature review on problem of coverage hole and their detection. Section III and IV is about problem formulation and terminologies we used in this paper. Section V contains our proposed detection algorithm for uncovered regions. Performance of algorithm is evaluated in section VI and section VII finally concludes the paper.

II. Related Work

Various algorithms for coverage preservation are proposed in [2-8] to maintain the maximum coverage of network for maximum time. These algorithms are mainly scheduling or routing algorithms. A dynamic event detection approach is proposed in [2] where statically deployed sensing nodes can adjust their sensing range. Lifetime of scheme and probability of event detection is analyzed and increased the network lifetime. Algorithm proposed in [3] is a remaining energy based scheduling algorithm where sensing nodes can go into sleep mode. This technique increased the network lifetime with hundred percent covered region. In [4] an algorithm called coverage aware clustering (CACP) where a new cluster head selection technique based on coverage cost is proposed. They also proposed a scheme for active nodes selection on the basis of layered self activation scheme. The main objective of maximized network lifetime is achieved in

spite of death of some sensing nodes. One other algorithm called ECDC is proposed in [5] in which they selected cluster head on the basis of coverage aware cost and residual energy. Some more coverage preserving algorithm are proposed in [6-8]. All the above discussed techniques have one common objective of maximum coverage lifetime. But a common drawback they are consisting of is that they do not have any technique for detection of coverage hole formation in WSNs.
Several coverage hole detection techniques are introduced in [9-16]. In [9], a hole detection strategy based on computational geometry is proposed for self organized wireless sensor networks. It is applicable for any irregular polygon. Another algorithm to spot uncovered regions is proposed in [10]. They used two kind of simplicial complexes for it. Major drawback of this technique is that it cannot spot triangsular coverage holes. A triangular oriented diagram for detection of hole and accurate calculation of its size is proposed in [11]. For restoration, they used incircle or circumcircle to find location of mobile sensors. Similarly in [12] they used Delaunay triangulation and empty circle properties to detect coverage hole. A clustering algorithm is also proposed to identify any kind of coverage hole. A homology based detection approach is proposed in [13]. They analyzed relationship of cech and rips complexes with respect of coverage holes for different sensing and communication radiuses. Results discussion shows that it is not capable to localize all coverage holes in network. A distributed hole detected protocol is proposed in [14] where they classified intersection points into covered and non-covered ones. On the basis of these points they detected coverage holes. Similar problem is tackled in [15] using distance calculation and number of transmitted messages. Each sensing node individually determines if it's a boundary node or non-boundary one using those intersecting points. A solution based on hop count measures is proposed in [16] which uses data traffic information for coverage hole detection. But shortcoming of this method is that it is unsuitable for largely scaled randomly deployed networks. All the above techniques have several lacks in detection procedure like skipped non-convex holes, inaccuracy in hole size detection, inaccurate calculation of hole location etc.

Our proposed algorithm can detect all kind of convex and non-convex coverage holes. In this method each sensing node will try to detect hole and after detection it will send the information to remotely situated base station. It can detect accurate location and exact size of uncovered region.

III. NETWORK MODEL

We assumed that a set of sensing nodes randomly deployed over a rectangular 2-D area A and all nodes are immovable after deployment. Each sensing node knows its location using GPS or any location information system. We considered sensing and communication range (R_s and R_c) for each node to be equal and are not changeable after deployment. When any sub area a of A is uncovered by sensing nodes then this uncovered area will be referred as coverage hole. We used binary model for communication, it means a sensing node is detectable inside R_c and undetectable its outside. Sensing model we used is also binary, it means area can be sensed inside R_s and cannot be sensed its outside.

IV. TERMINOLOGIES

Following are the terminologies we used through this work:

Definition 1 (Target area): We considered a target area A that is needed to be sensed by sensing nodes. If whole target area is covered by sensing nodes then there is no coverage hole in A. We used rectangular area in this work.

Definition 2 (Neighbor nodes): All the sensing nodes that are within the sensing range of a node S are referred as neighbor nodes of S denote by N(S)

$$\{N_i \epsilon N(S) \| N_i S| < 2R_s\}$$

Definition 3 (Intersection point): A point P is called as an intersection point I_p if

It is situated on boundary line of two sensing nodes S_i and S_j, i.e.$|I_pS_i| = |I_pS_j|$ = Rs.

OR

It is situated on boundary line of sensing nodes S_i and target area A.

Intersection points between sensing nodes:-

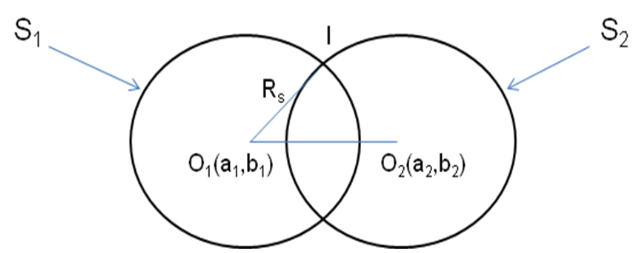

Fig. 1: Intersecting sensing nodes S_1 and S_2

$$\mathbf{O_1O_2} = \sqrt{(a_2 - a_1)^2 + (b_2 - b_1)^2}$$

Intersection points between S_1 and S_2 exists only if $O_1O_2 < 2R_s$ and $O_1O_2 \neq 0$

Equation for sensing nodes $\mathbf{S_1}$ and $\mathbf{S_2}$ is:

$(\mathbf{X-a_1})^2 + (\mathbf{Y-b_1})^2 = \mathbf{R_s}^2$ and $(\mathbf{X-a_2})^2 + (\mathbf{Y-b_2})^2 = \mathbf{R_s}^2$

With the help of these equations we can find out intersection points between sensors.

Intersection points between sensing node and boundary of the region:-

Line's equation for any two points (X_1, Y_1) and (X_2, Y_2) is –

$$\mathbf{Y} = \frac{(Y_2 - Y_1)}{(X_2 - X_1)}\mathbf{X} + \mathbf{b}$$

Where **b** is the intersection point over Y-axis.

Sensing circle's equation will be –

$$(\mathbf{X} - \mathbf{a})^2 + (\mathbf{Y} - \mathbf{b})^2 = \mathbf{R_s}^2$$

Where (a, b) are coordinates of sensing node and R_s is radius of sensing.

With the help of these equations we can find out intersection points between sensing node and target area's boundary line.

Definition 4 (Crucial Boundary Points (CBP)): Any intersection point I_p will be called as Crucial Boundary Point(CBP) if it is not covered by any sensing node than intersecting ones.

Definition 5 (Coverage hole): When any sub area of the target area A is uncovered by sensing nodes then that particular sub area is called as coverage hole. Two kind of coverage holes can occur in network. First is close coverage hole that is completely surrounded by sensing nodes and second one is open coverage hole where at least one of its edges is surrounded by target area A.

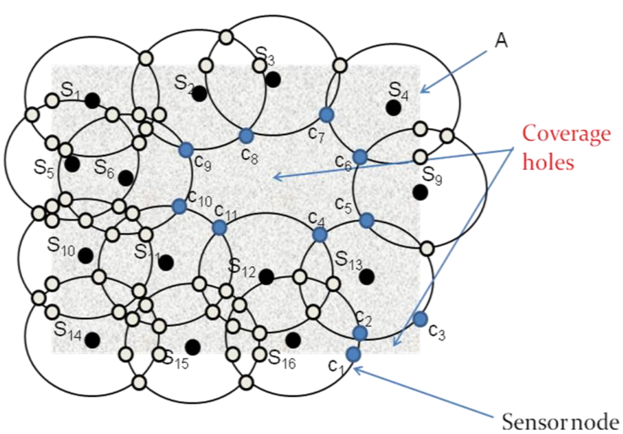

Fig. 2: Wireless Sensor Network with Coverage Holes.

In figure 2, sensing nodes $\{S_1, S_2, S_3, \ldots\ldots, S_{17}\}$ are deployed randomly in a target area A. Nodes S_2 and S_5 are neighbors of S_1 where $|S_1\ S_2|$ and $|S_1\ S_5|$ are less than $2R_s$ and R_s is sensing range. Intersection Points $\{c_1, c_2, c_3\}$ and $\{c_4, c_5, \ldots\ldots, c_{11}\}$ are Crucial Boundary points (CBPs) and form an open and closed coverage holes respectively.

V. Proposed Algorithm

This section contains our proposed algorithm in which we present a new approach for detection of uncovered areas in Wireless sensor network. First of all every node will try to find out Crucial Boundary Points (CBPs) with its neighborhood nodes. Then group those CBPs to find the exact size of coverage hole as well its location in network. Detailed approach is given below.

Algorithm for detection of coverage hole:-

```
Input: S: Set of all sensing nodes;
Output: SCBP: Set of CBPs forming coverage hole;
1. Initialize Si to a value equal to total number of deployed sensing nodes;
2. Initialize SCBP = ϕ;
3. If (S ≠ ϕ)
   {
       Select a sensing node Si from set S and obtain its sensing neighbors Ni(Si);
       Make a list of node's neighborhood nodes and sort them in anti-clockwise;
       Obtain a list of intersection points(Ip) with its sensing neighbor nodes and the target
       area;
       Check all Ip for CBP and remove all non-CBPs;
       If (CBP found)
       {
           If (SCBP ≠ ϕ)
           {
               If (the starting crucial boundary point(bi) is revisited || boundary of the
               target area is touched)
               {
                   Connect every consecutive Crucial Boundary Point(bi) along the
                   boundary of sensing nodes having bi and EXIT;
               }
               Else
               {
                   Add the Crucial Intersection point to set SCBP and
                   Select Crucial neighbor node and
                   Go to step(2);
               }
           }
           Else
           {
               Add the crucial boundary point to set SCBP and
               Select crucial neighbor node and
               Go to step(2);
           }
       }
   }
```

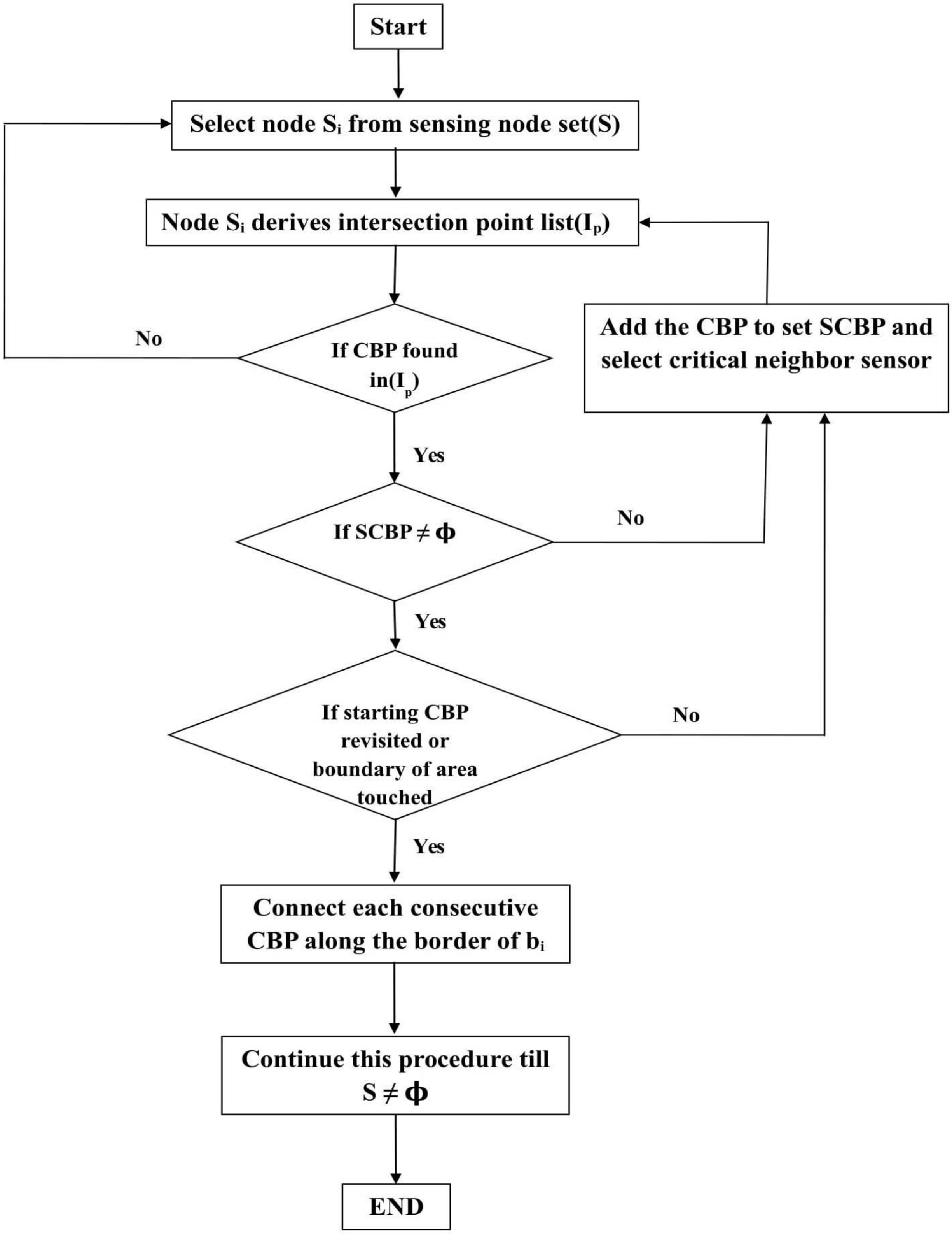

Fig. 3: Flow chart for detection of coverage hole algorithm.

VI. Performance Evaluation

In this section, performance of the above proposed algorithm is evaluated in terms of detection of exact coverage hole size, accurate location in the network and the time it requires for detection. We compared this algorithm with an existing detection algorithm called Hole Detection using Boundary Critical Points (HDBCP) [17]. Simulation setup and results are discussed below.

VI.I Simulation Setup

Our algorithm is simulated over MATLAB R2014a with randomly deployed sensing nodes. Sensing and communication range are equal (R_s=R_c) and are fixed at 10 m. Equal sensing and communication range will reduce the energy consumption of network. Radio model is IEEE 802.15.4. Each sensing node is GPS enabled to get its location information. There is a random generation of coverage holes in network.

VI.II Simulation Results

Result 1: Analysis of area detected as coverage hole

We randomly deployed 100 to 500 sensing nodes in a rectangular target area and coverage holes will be randomly generated in network. Simulation results in figures 3-7 show that our algorithm detected all kind of convex and non-convex coverage holes with exact size and their accurate locations in network.

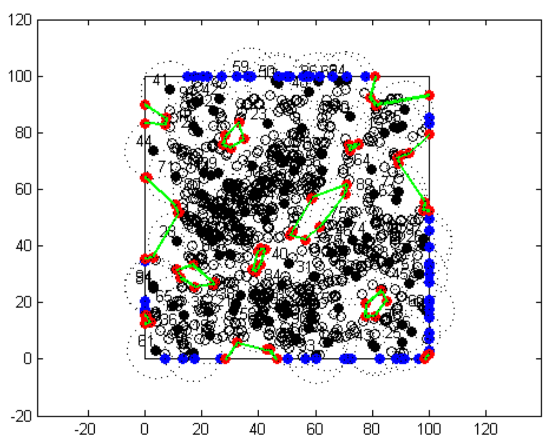

Fig 3: Detected coverage holes in WSN for 100 nodes.

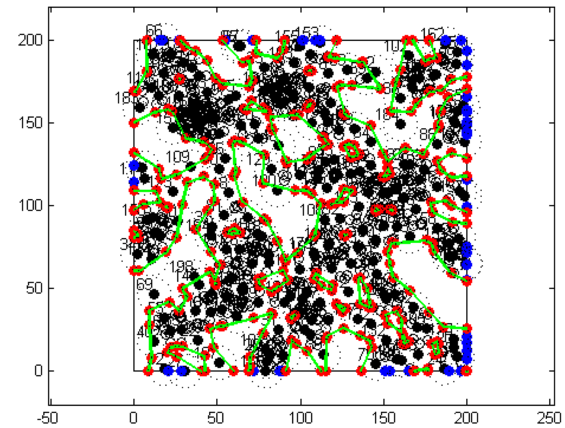

Fig 4: Detected coverage holes in WSN for 200 nodes.

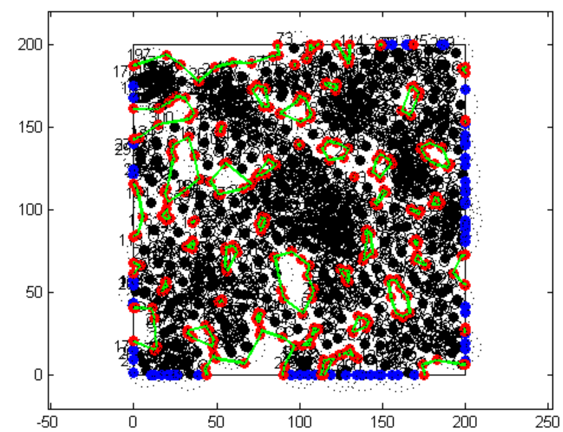

Fig 5: Detected coverage holes in WSN for 300 nodes.

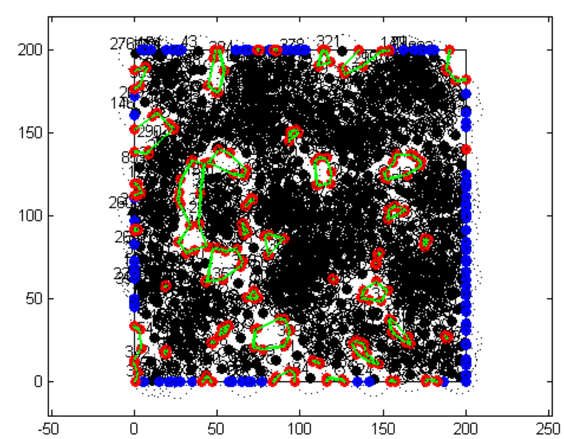

Fig 6: Detected coverage holes in WSN for 400 nodes.

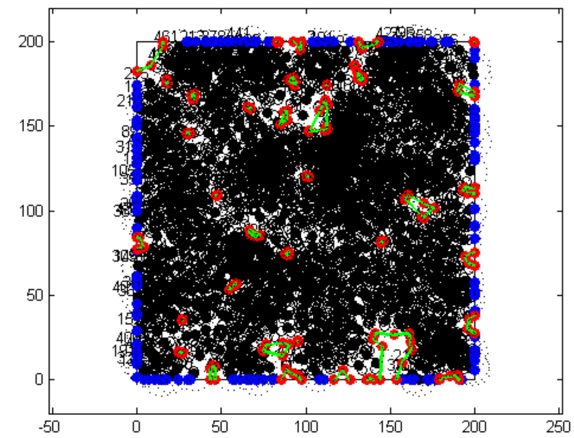

Fig 7: Detected coverage holes in WSN for 500 nodes.

Result 2: Analysis of Time taken for hole detection

We randomly deployed 100 to 1000 nodes in a 200×200 m^2 target area. Coverage holes will be generated randomly in network. Simulation results in figure 4 show that our algorithm takes little bit less time than HDBCP. It is shown that if the number of nodes increases for the same target area the number and size of coverage holes will decrease that will cause decreased detection time.

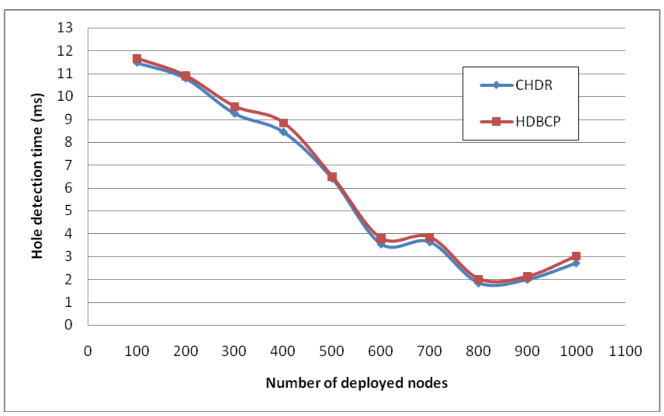

Fig. 8: Comparison of time taken for hole detectction using CHDR and HDBCP.

VII. Conclusion and Future Work

In this paper we have given a new approach for detection of coverage holes in sensor network. Our proposed approach is based on intersection points between sensing nodes and between sensing nodes and target area. Simulation results show that it can detect all convex and non-convex holes in network. It can estimate exact size of coverage holes with their exact locations in network. It is also shown that our algorithm is better that HDBCP in terms of time taken for hole detection. In future we will try to recover those detected holes with minimum number of sensing nodes. We will also try to reduce its complexity in terms of hole detection time.

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Authors Profile

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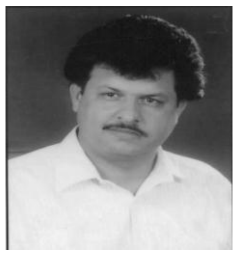

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