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Coverage Gaps Discovery and Reclamation (CGDR) in Remote Wireless Sensor Networks

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Abstract*: wireless sensor network comprise of some tiny sensing hubs which are outlined to work in a targeted locale. Coverage conservation is an ultimate necessity of remote wireless sensor networks to effectively convey certain services. Sensing hubs are equipped with constrained battery power that's a major concern in this field. Amid network working, a few of the sensing hubs get pass on since of energy exhaustion which can create a specific region unattended. We allude this unattended region as coverage gap. A few other reasons for coverage gap are hub failure, link miscarriage etc. We propose a Coverage Gap Discovery and Reclamation (CGDR) algorithm as solution for this coverage gap issue. CGDR uses location coordinates of deployed hubs to identify and reclaim those coverage gaps. Performance evaluation shows that our proposed algorithm performs better in terms of gap discovery time and number of hubs required for its reclamation. CGDR can ensure full coverage reclamation for all kind of convex and non convex gaps of the network.

Index Terms*: Remote Wireless Sensor Networks, Coverage preservation, Coverage gap problem, Coverage gap discovery, Convex coverage gaps, Non-convex coverage gaps, Coverage gap reclamation.

I. INTRODUCTION

Remote Wireless Sensor Systems comprised of little battery worked sensor hubs are outlined to provide valuable information for applications like interruption discovery, reconnaissance frameworks, environment observing, etc. [1]. Sensing hubs can be deployed arbitrarily or physically in a specific target region to gather, process and send the detected information to remote base station. Basic applications like interruption discovery and war zone reconnaissance frameworks require full coverage over target region to make it work viably. Amid network operation, energy exhaustion may cause a few sensor hubs die that will result in fractional breakage of coverage within the network. It is alluded as an issue of coverage gaps in remote sensor networks [1, 2]. Performance of the sensor network is extremely affected by these coverage gaps. Subsequently, an effective algorithm for discovery and reclamation of these coverage gaps is profoundly required.

A few algorithms for coverage conservation have been proposed [1-4] to extend the coverage lifetime of remote sensor networks. A few Coverage conscious scheduling techniques are proposed in [1, 2] to extend coverage lifetime by adjusting energy utilization within the network. In [3, 4], coverage and energy conscious clustering techniques are proposed where a sensor hub with totally covered detecting region is chosen as cluster head to course the data. Dyeing of these cluster heads don't make any coverage gap within the network since their sensing region is totally secured by their neighbour hubs. But after going through numerous communication rounds a few more hubs get down those comes about in inescapable coverage gaps. A few more techniques for coverage conservation are detailed in [5-7] but they need in coverage gaps discovery hence missing reclamation methods. A few analysts proposed a few coverage gap discovery methods that are detailed in [8-15] but they don't give any reclamation technique.

Our primary focus of this work is to devise a new technique to discover and reclaim coverage gaps in remotely situated WSNs. A Significant Crucial Meeting points (CMPs) based technique is proposed which may be a modern concept. The solution we proposed can be part up into two parts: (1) A localized coverage gap discovery algorithm based on Crucial Meeting Points (CMPs) and (2) A coverage gap reclamation algorithm that's a combination of perpendicular bisection of a line strategy and midpoint based location identification algorithm.

The remaining parts in this paper are organized as takes after: Section 2 surveys the related work on coverage gap - description, discovery and reclamation. Section 3 gives points of interest of issue definition and phrasings we used in this paper. Section 4 describes our proposed coverage gap discovery and reclamation algorithms. Performance is evaluated in section 5 and at last section 6 concludes the paper.

II. RELATED WORK

A few algorithms for coverage conservation have been introduced in [1-7] to extend the coverage lifetime of sensor networks. Those algorithms are basically coverage conscious scheduling and clustering algorithms. In [1], an on-demand k-coverage method for dynamic event detection is proposed where detecting range of static sensors can be balanced amid their transmission time. Likelihood of event discovery and scheme lifetime is analysed and concluded that the network lifetime is increased. In [2], a sensor scheduling algorithm based on leftover energy is proposed in which sensing hubs can be put into activated or rest mode. Purpose of this algorithm is to achieve most extreme network lifetime with completely secured target locale. A coverage conscious clustering convention called as CACP is proposed in [3].

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In this technique, cluster head is selected on the basis of coverage aware cost metric and a layered self actuation plot for active hubs determination is proposed. Increased lifetime of network is achieved in spite of passing of few sensor hubs. One more coverage conscious and energy aware technique called as ECDC is detailed in [4]. In this, they selected cluster heads on the premise of leftover energy and coverage conscious cost metric. Some other coverage conservation techniques are too detailed in [5-7]. All of the above techniques are outlined to increase the coverage lifetime of the network. But they have a need of any methodology to discover coverage gap formation as well as their reclamation within the network.

Various algorithms for discovery of coverage gaps are proposed in [8-15]. In [8], a computational geometry based approach for coverage gap discovery has been proposed which is outlined for self organized sensor networks. It is applicable for any kind of unpredictable polygon shaped locale. Algorithm [9] adopted cech and rips complex based to find out the coverage gaps. Major drawback of this scheme is that it can identify only non triangular gaps not triangular ones. In [10], a triangular shaped structure is introduced to detect and calculate the size of coverage gap. For reclamation, circumcircle or incircle type methodology is used to decide target localization for portable sensing hubs. But it does not guarantee full coverage reclamation with optimal number of hubs. In [11] a comparable issue is handled by utilizing Delaunay triangulation based approach. Characteristics of empty circle are utilized for identification of coverage gap. A separate clustering method for boundary hubs is given in it to recognize all kind of coverage gaps. In [12], a homology based technique for discovery of coverage gap is introduced. Simulation results show that the algorithm isn't able to discover all different kind of coverage gaps. In [13], a dispersed coverage gap detection technique is proposed. Intersection points between hubs are calculated and clubbed into secured and not secured ones. On the premise of these crossing points coverage gaps in network are detected. In [14], a methodology for the same issue is displayed by utilizing basic distance calculation and minimization of the messages transmitted. Verification of Meeting points by hubs decides if it's a boundary hub or not. Same issue is handled in [15], in which a hop count measures based solution is presented. It utilises only basic information activity data to detect coverage gaps within the network. But the major deficiency is that it isn't appropriate for huge scaled arbitrarily deployed sensor networks. Methodologies that we have discussed above consist of one common deficiency that no method is introduced to overcome coverage gaps issue.

A few other techniques for reclamation of coverage gaps are too introduced in [16-23]. In [16], a simplicial complexes based method for coverage gap discovery and fixing is proposed. Perpendicular bisection strategy is utilized to fix the coverage gaps. It will work viably even if partial information of hubs coordinates is available. But the Number of patching hubs required are not minimal since of redundancy of deployed patching hubs. Similar issue is handled in [17, 18] utilizing portable sensor hubs. But those are not reasonable for simply statically deployed remote sensor systems. An intersection points based algorithm is proposed in [19]. For patching of coverage gaps perpendicular bisection of line between crossing points is used. They didn't consider the situation of not secured gaps and reclamation solution is additionally not optimal. Algorithms proposed in [20, 21] are based on rearrangement of sensor hubs but those are not pertinent for static sensor networks. In [22], they reclaimed coverage gaps by increasing the sensing range of sensing hubs. Target locale is partitioned into cells and classify them secured or not secured ones. Sensor which has higher residual energy is given higher priority for reclamation by increasing its sensing range. But it isn't suitable for systems where sensing range is unalterable. In [23], a tree-based method for detection of coverage gaps is proposed. They dissected a huge gap into a few littler ones and decided patching area for each sub coverage gap individually. Shortcoming of this strategy is that the impact of little coverage gaps on network's performance is ignored. All the above discussed methods don't show an ideal solution to discover and reclaim coverage gaps of the network.

Some additional benefits of our proposed algorithm(CGDR) are:

i. A coverage gap discovery technique in which each hub sends its location information to base station and then the exact location and size of gap calculated. It shows its zero tolerance behaviour towards coverage gaps identification.

ii. Any kind of convex or non-convex gaps can be identified as well as reclaimed efficiently.

iii. A new approach for patching hub's location calculation on the basis of largely distance situated crucial meeting points.

III. NETWORK MODEL AND TERMINOLOGIES

The Network model and phrasings we used in this work are displayed in this segment.

1.1. Network Model

Let suppose a 2-dimensional Region of Interest R_i deployed with sensing hubs (S_1, S_2,……….., S_n). All the sensing hubs are statically deployed and they are aware of their geographic location via any location information system. Sensing and communication range of each node is immutable and is considered to be equal (R_s=R_c). If any sub region S_r of R_i is uncovered by any sensing hub then that specific sub region will be considered as coverage gap. Model used for communication is binary where a sensing hub is recognizable inside interior circle of communication range R_c and cannot be recognized in exterior side. Model used for sensing is also binary where the area is detected when inside the detecting range R_s and cannot be detected exterior side.

1.2. Terminologies

Terminologies we used amid the whole process of designing this method are as :

Definition 1: *(Region of Interest)* - Region of Interest R_i is a particular area that is needed to be sensed by sensors. If no sub region inside R_i is uncovered by sensing hubs then there are no coverage gaps exist in it. We used a rectangular shaped area for evaluation purpose.

Definition 2: *(Sensing Neighbour Hubs)* - All the sensing hubs that are within the reach of detection range of a hub S will be called as the sensing neighbour hubs of S and will be signified as $N_b(S)$.

$\{S_i \epsilon N_b(S) \mid |S_iS|<2R_s|\}$

Definition 3: *(Meeting points)* - Any point P will be referred as meeting point only if -

It exists on the perimeter of two sensing hubs S_i and S_j, i.e.$|PS_i| = |PS_j| = R_s$.

OR

It exists on the perimeter of a sensing hub S_i and border line of region of interest R_i.

a) Meeting points of two sensing hubs:-

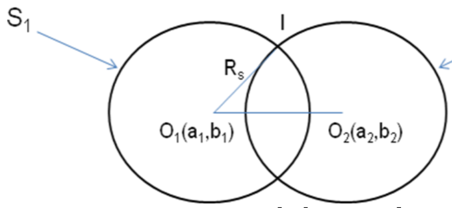

Fig.1. Intersecting sensing hubs S_1 and S_2

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

Existence of Meeting points is only if $O_1O_2 < 2R_s$ and $O_1O_2 \neq 0$

Equation of both sensing nodes $\mathbf{S_1}$ and $\mathbf{S_2}$ will be:

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

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

Using above calculations we can find out meeting points between sensing hubs.

b) Meeting points of sensing hubs and border line of the targeted region:-

Equation of line between two points (X_1, Y_1) and (X_2, Y_2) will be –

$$\mathbf{Y} = \frac{(Y_2-Y_1)}{(X_2-X_1)}\mathbf{X + b}$$ Where **b** is the intersection point situated on Y-axis.

Equation for circle of detection range will be –

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

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

Using above calculations we can find out meeting points of sensing hub and border line of region of interest R_i.

Definition 4: *(Crucial Meeting Points (CMPs))* - A meeting point P will be qualified as Crucial Meeting Point (CMP) if it is uncovered by all the deployed sensing hubs.

Definition 5: *(Coverage Gaps)* - If a sub region r of region of interest R_i is uncovered of all the sensing hubs then this uncovered sub region will be referred as coverage gap. These Coverage gaps can be closed or open. Gaps which are completely encompassed by sensing hubs will be referred as closed coverage gaps whereas gaps which have at least one of its edges encompassed by border line of region of interest R_i will be referred as open coverage gaps.

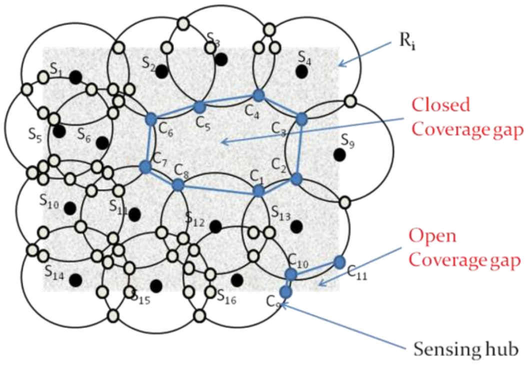

Fig.2. Remote Wireless Sensor Network with Coverage gaps.

In figure 2, sensing hubs $\{S_1,S_2,S_3,\ldots\ldots.,S_{15}\}$ are deployed arbitrarily over a region of interest R_i. Sensing hubs S_2 and S_5 are sensing neighbour hubs of S_1 because $|S_1,S_2|$ and $|S_1,S_5|$ is less than $2R_s$ where R_s is the radius of the perimeter of detection range of a hub. $\{C_1,C_2,C_3,\ldots\ldots.,C_8\}$ and $\{C_9,C_{10},C_{11}\}$ are Crucial Meeting Points (CMPs) as they are not covered by any sensing hub other than their corresponding meeting ones. CMPs $\{C_1,C_2,C_3,\ldots\ldots.,C_8\}$ form a closed coverage gap and CMPs $\{C_9,C_{10},C_{11}\}$ form an open coverage gap within the network.

IV. PROPOSED ALGORITHM

Our proposed Coverage Gap Discovery and Reclamation (CGDR) algorithm has two parts. First one is for coverage gap discovery where we utilized Crucial Meeting Points (CMPs) based strategy to identify correct uncovered locale which is unattended by any sensing hub. Second one is for reclamation of that coverage gap by finding optimum location of patching hub using perpendicular bisection of a line method.

1.1. Coverage Gap Discovery

We assumed that each sensing hub knows its location by using any location information system. Hubs exchange their location information with their neighbors to know neighbors location. For detection of coverage gap each sensing hub will find out crucial meeting points between its neighbor hubs and itself. With the help of these meeting points it'll discover out the exact uncovered region called as coverage gap. Detailed procedure is given below -

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Algorithm for Coverage Gap Discovery:-

```
Input: S: Set of all sensing hubs;
Output: C: Set of all Crucial Meeting Points (CMPs);
1. Initialize Si to a predetermined integer number;
2. Initialize C = ϕ;
3. If (S ≠ ϕ)
    {
        Select a sensing hub Si from S and get a set of adjoining sensing neighbour hubs Nb(Si);
        Create a clockwise sorted list of node's sensing neighbour hubs;
        Obtain a set of meeting points(Pi) with its sensing neighbour hubs and the target locale;
        Check all Pi for CMP and remove the non-CMPs;
        If (CMP found)
        {
                If (C ≠ ϕ)
         {
                        If (the beginning crucial meeting point(Ci) is revisited || boundary of the target locale is touched)
                        {
                                Connect all continuous Crucial Meeting Points(Ci) along the border line of hubs having
                                Ci and EXIT;
      }
           Else
           {
              Add the Crucial Meeting point to set C;
              Select a Crucial sensing neighbour hub;
              Go to step(2);
           }}
         Else
         {
                        Add the Crucial Meeting point to set C;
           Select a crucial sensing neighbour hub;
      Go to step(2);
    }}}
```

1.1. Coverage Gap Reclamation

After discovering the exact coverage gap in network it should be reclaimed with optimum number of new sensing hubs. To reclaim it optimally we got to find out the optimal area for new sensing hubs deployment. We used bisection strategy of line to get coordinates of new hub's patching location. A line between two maximal distance situated CMPs from the stored ones will be drawn. Detailed procedure is given below –

Algorithm for Coverage Gap Reclamation:-

Input: C: Set of all Crucial Meeting Points (CMPs);
Output: Coordinates for new patching node;
1. Initialize **(Euclidian distance set)**$D_{ij} = \phi$;
2. Input a point C_i from **C**;
3. Select next adjoining point C_j in clockwise;
4. Calculate $|C_i$ to $C_j|$;
5. If $(|C_i, C_j| \leq 2R_s)$
{
Add $|C_i, C_j|$ **to** D_{ij};
Add 1 to j and;
Go to step 4;
}
Else
{
Select **maximal distance from** D_{ij} and
find two points N_1 & N_2 on the bisection line of corresponding b_ib_j such that $N_1C_i = N_1C_j = R_s$ & $N_2C_i = N_2C_j = R_s$;
}
6. If N_1 is already secured by any of the sensing hubs OR outside the target region
If N_2 is already secured by any of the sensing hubs OR outside the target region
Deploy a new sensing hub S_n on the **Midpoint of** b_ib_j;
Else
Deploy a new sensing hub S_n on N_2;
Else
Deploy a new sensing hub S_n on N_1;
7. Add sensing hub S_n to set S and run **Coverage Gap Discovery algorithm** from step **3**;

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V. PERFORMANCE EVALUATION

In this section, we evaluated the performance of our proposed algorithm CGDR in terms of time consumption for detection of coverage gaps and number of sensing hubs required for reclamation of those gaps. We also compared our algorithm with the boundary critical points based detection algorithm HDBCP and perpendicular bisector based patching algorithm HPBCP [20]. Other details like simulation setup and results are described as follows.

1.1. Simulation Setup

simulated our algorithm using MATLAB R2014a for a random deployment of 100 to 1000 sensing hubs. We considered sensing range equal to the communication range fixed at 10 m to reduce the energy consumption of network. The radio model we used is IEEE 802.15.4. All hubs are GPS enabled to collect its location information. Coverage gaps are generated randomly in the network.

1.2. Simulation Results

Result 1: Analysis of Coverage Gap Reclamation

We made a random deployment of 100 sensing hubs over a 100×100 m^2 rectangular region of interest and generated some random coverage gaps in the network. Figures 3 to 9 show that our CGDR algorithm reclaimed all coverage gaps successfully and achieved 100% coverage for the selected region after second iteration. Whereas, HPBCP has not reclaimed all coverage gaps and also not achieved 100% coverage for the same. It clearly shows that newly patched hubs using CGDR algorithm are securing maximum possible area of coverage gaps cause of best selection of CMPs.

Iteration 1:

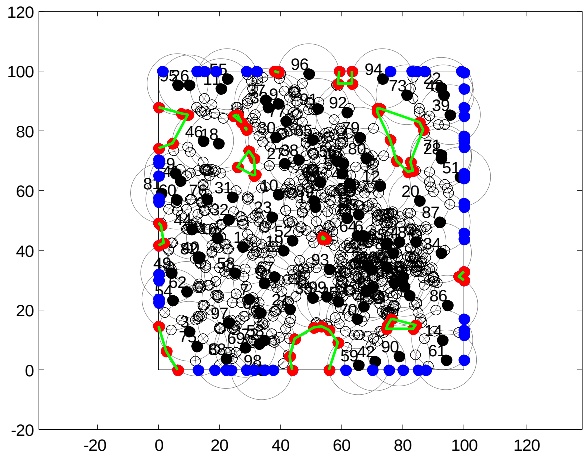

Fig.3. Initial coverage gaps in Remote WSN.

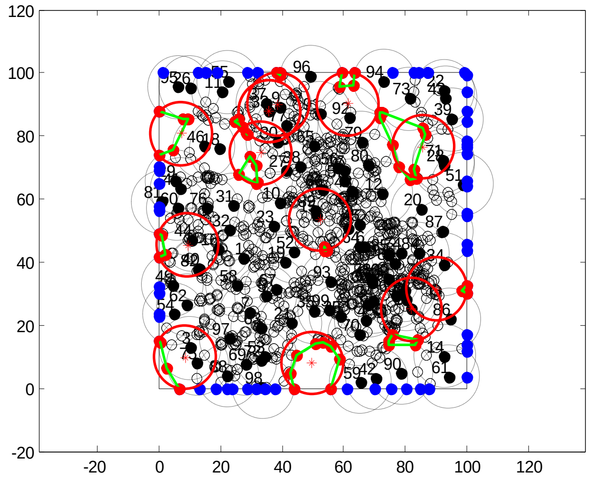

Fig.4: Coverage gaps reclamation using HPBCP

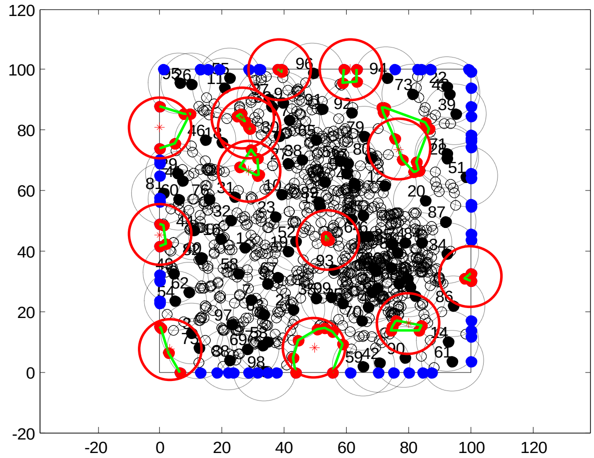

Fig.5. Coverage gaps reclamation using CGDR.

Iteration 2:

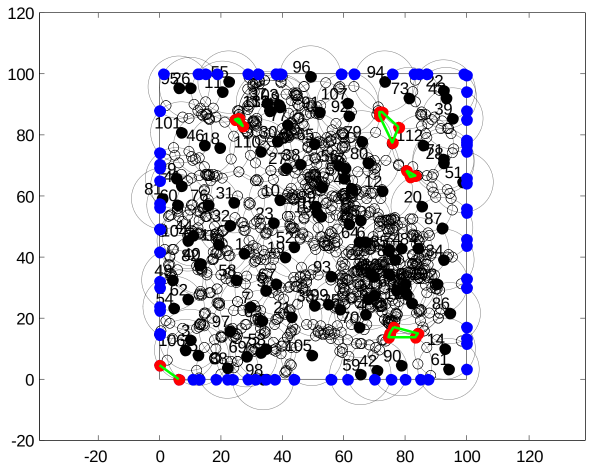

Fig.6: Coverage gaps after iteration 1 of using HPBCP.

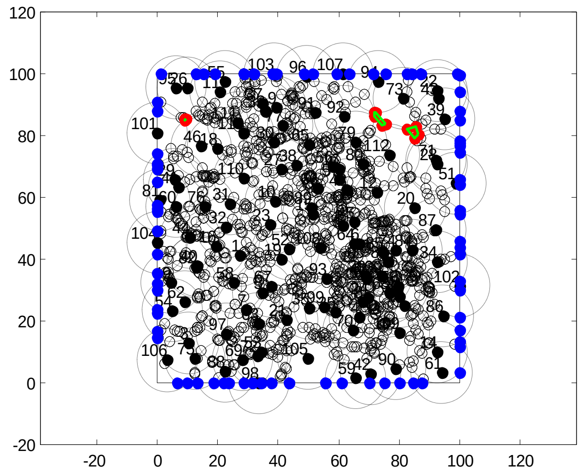

Fig.7. Coverage gaps after iteration 1 of using CGDR.

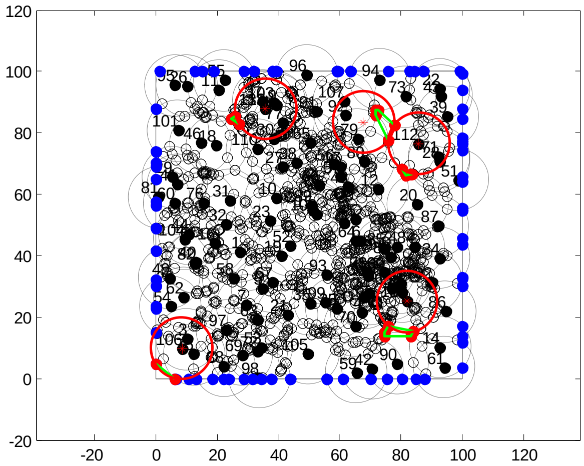

Fig.8: Coverage gaps reclamation using HPBCP.

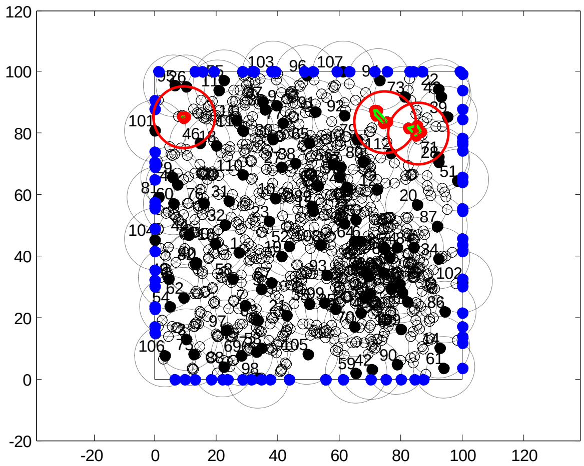

Fig.9. Coverage gaps reclamation using CGDR.

Result 2: Analysis of Coverage Gap Reclamation Time

We deployed 100 to 1000 sensing hubs randomly over a 200×200 m^2 region of interest. This random deployment will generate random coverage gaps in the network. Simulation of our coverage gap discovery algorithm shows that it identified all convex and non-convex gaps accurately. Figure 10 shows that the time required for gap discovery using CGDR is less than the time required by HDBCP. It is observed that when the number of deployed hubs increases in the same target region the number and size of coverage gaps decreases hence the discovery time decreases.

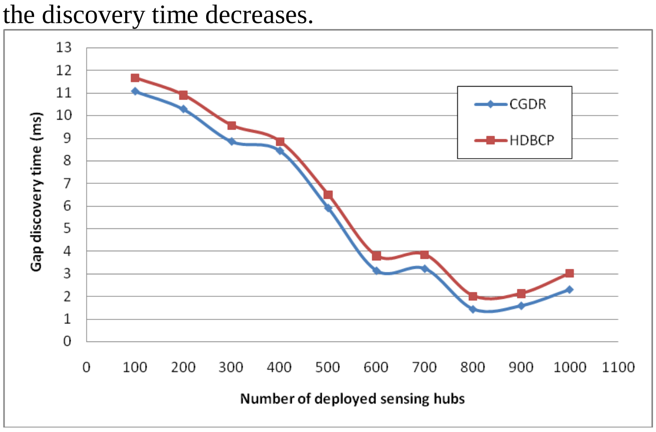

Fig.10. Comparison of gap discovery time using CGDR and HDBCP.

Result 3: Analysis of Required Patching Hubs

As shown in figure 11 to 13, it is observed that the number of required hubs for restoration using CGDR is less than the required nodes using HPBCP. It is due to the selection of best CMPs for patching hub's location calculation which plays a major role in number of required hubs. These figures show that our CGDR algorithm outperform HPBCP in terms of required patching hubs. It is also observed that the number of required hubs decreases as the number of deployed hubss increases due to the decrease in number and size of coverage gaps.

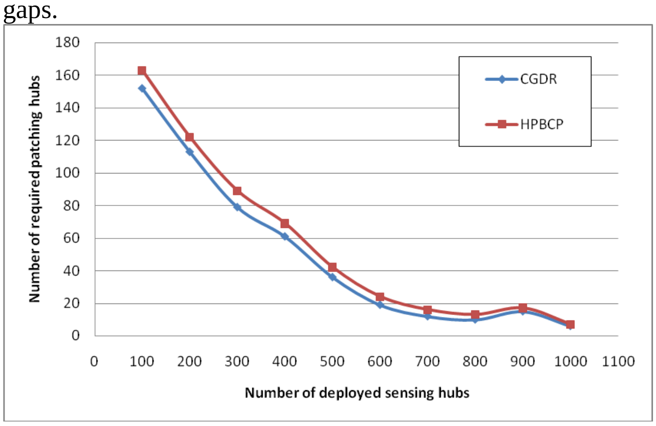

Fig.11. Comparison of required hubs for gap reclamation using CGDR and HPBCP (Iteration 1).

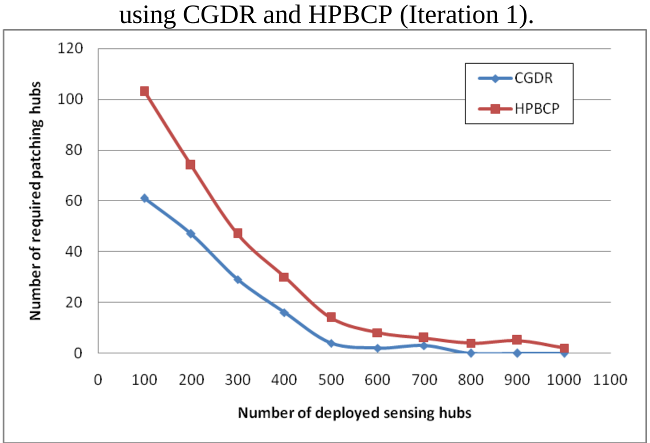

Fig.12. Comparison of required hubs for gap

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reclamation using CGDR and HPBCP (Iteration 2).

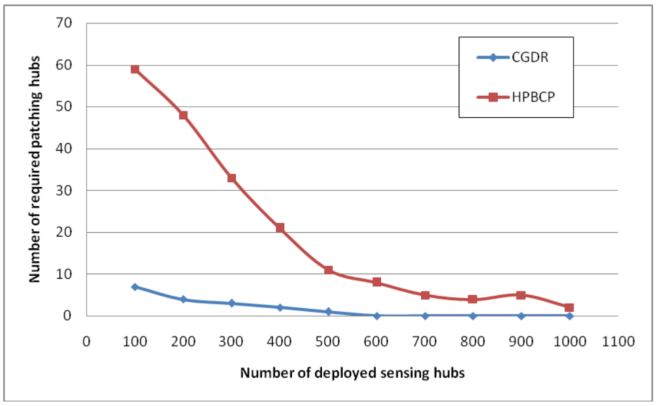

Fig.13. Comparison of required hubs for gap reclamation using CGDR and HPBCP (Iteration 3).

VI. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a Coverage Gap Discovery and Reclamation (CGDR) algorithm for precise identification and proficient reclamation of coverage gaps in remotely situated WSNs. We have given a different approach for patching hub's location calculation on the basis of largely distance situated CMPs. Simulation results showed that our algorithm can detect any kind of convex and non-convex gaps in the network. It also achieved 100% coverage after reclamation which is quite effective in respect of critical applications like interruption discovery, reconnaissance frameworks, environment observing, etc. The number of required patching hubs are also minimal that will make a significant impact on patching cost of network. It is applicable for any kind of polygon formed locale. Our future works include reducing the complexity of this algorithm and make it more acute for largely scaled remote WSNs.

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