Redundancy Elimination with Coverage Preserving Algorithm in Wireless Sensor Network

Shobha Biradar[1] and Mallikarjuna Shastry[2]

[1]Department of Computer Science and Engineering, REVA Institute of Technology, Bengaluru, India
[2]School of Computing and Information Technology, REVA University, Bengaluru, India

***Abstract*:** In Wireless Sensor Network, the sensor nodes are deployed using random or deterministic deployment methods. Many applications prefer random deployment for deploying the sensor nodes. Random deployment is the main cause of redundancy. Detection and elimination of redundant sensor nodes while preserving coverage is very important issue after the sensor nodes are deployed randomly in the region of interest. The redundancy elimination with coverage preserving algorithm is proposed in this paper and the results are presented. The proposed algorithm determines redundant sensor nodes and also the sensor nodes which provide the least coverage of region of interest. If two sensor nodes cover same area or if the Euclidian distance between two nodes is less than 25% of sensing range of a sensor node, the sensor which is not located at optimal position will be deactivated, so that, it reduces the number of optimal nodes required to cover complete region of interest. This in turn increases the lifetime of the network. The simulation results illustrate that the proposed algorithm preserves 100% coverage or region of interest by removing redundant nodes and also the nodes which provide the least coverage of region of interest. It also reduces the number of optimal nodes required to provide 100% coverage of region of interest.

***Keywords*:** Coverage, Random Deployment, Redundancy, Sensor Nodes, Wireless Sensor Network.

1. Introduction

Wireless sensor network (WSN) comprises of one or more base stations and number of nodes called wireless sensors. The environmental conditions like pressure, sound, humidity, moisture and temperature are monitored by these sensor networks and the necessary data are transmitted to the desired locations through the WSN. Two different methods are used for deployment of sensor nodes in WSN. They are deterministic and random. In deterministic deployment method, the region of interest (RoI) can be covered completely as the optimal locations of sensor nodes are known in advance.

Hence, with deterministic deployment method, 100% coverage can be obtained with minimal number of nodes. This kind of deployment does not suffer from the problem of same area being covered by more than one sensor and there will be no sensor nodes with least coverage of region of interest. But, use of deterministic deployment method in a battlefield or in a disaster region will have high risk and it is infeasible also.

Thus, random deployment method is chosen for such applications, where, the nodes are deployed from aircraft randomly in the given region of interest. But, in this method, optimal locations, where sensor nodes are to be deployed exactly are not known prior to random deployment. As a result of random deployment, few places are covered with more sensor nodes and few other places are covered with less sensor nodes. It results in creation of coverage holes in region of interest and hence the region of interest cannot be covered completely. These coverage holes can be removed by identifying the optimal positions for placement of sensor nodes and moving the sensor nodes which are closest to optimal positions. So, after random deployment, any of the coverage enhancement algorithms can be used to compute optimal positions of sensor nodes in region of interest [1].Later, the sensor nodes which are closest to optimal positions are moved to optimal positions [1].

But, once the sensor nodes are moved from their original random position to the optimal positions, there are chances that, same position/location may be covered by two or more sensors. This process results in overlapping of sensor nodes and causes redundancy [2]. Redundancy has both advantages and disadvantages. Increased data accuracy, sensing reliability, lifetime of Wireless Sensor Network (WSN) and security are some of the advantages of redundancy. But, exhaustion of energy for receiving data, transferring replicated data and unnecessary execution of repetitive tasks are some of the disadvantages of redundancy.

Redundancy elimination eliminates the transferring of replicated data and unnecessary execution of repetitive tasks. It also saves large amount of energy consumption, because, very less number of nodes will be active at any point of time and less number of sensors which are closest to optimal positions are moved. Further, maintenance of the WSN without redundant nodes and the nodes which provide least coverage of RoI will be very inexpensive [3].

The research work carried out so far indicates that there is a scope for elimination of redundancy, while preserving 100% coverage of region of interest. Hence, it is required to develop an efficient technique to eliminate the redundancy while preserving the 100% coverage of given region of interest.

We have designed and developed a Redundancy Elimination with Coverage Preserving Algorithm (RECPA) in Wireless Sensor Network to eliminate the redundancy completely while preserving the 100% coverage. The main goal of our RECPA is to identify redundant sensor nodes and sensor nodes which provide least coverage of region of interest. Such nodes are deactivated or they are put in sleep mode by using the following method.

Euclidian distance between the sensor node positioned at optimal position and its neighboring node is computed. If the Euclidian distance is less than 25% of sensing range of a sensor, the neighboring node is considered as redundant node and hence it is eliminated. This is repeated for all the neighboring nodes of each sensor positioned at optimal position. Thus, RECPA eliminates both redundant nodes (Euclidian distance is 0 (zero)) and nodes which provide least coverage of region of interest (Euclidian distance is less than or equal to 25% sensing range of a sensor).Since, RECPA eliminates both redundant nodes and even the nodes which provide least coverage of region of interest, it significantly reduces the optimal number of nodes required to provide 100% coverage of given region of interest. Thus, RECPA eliminates the redundancy completely and preserves 100% coverage of region of interest. The organization of the paper is as follows. Literature review/related work is discussed in section 2, system model used for the implementation of proposed algorithm is described in section 3, proposed algorithm is presented in section 4, the results are presented in section 5, conclusions are drawn in section 6 and future work is presented in section 7.

2. Related Work

A Lot of research work has been carried out in Wireless sensor area network to address coverage, connectivity and redundancy.

The authors in [4] developed a modified version of Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm to determine redundancy in a given region of interest, after random deployment of sensor nodes in WSN. The redundancy which arises due to coverage of same area by more than one sensor node is considered in this approach. The redundant nodes which cover the same sensing field are identified and a proper scheduling scheme is implemented for better utilization of the energy resources of sensor nodes which in turn increases the life time of the wireless sensor network. The capabilities of LEACH algorithm are extended by adding a new routine for identification of redundant sensor nodes deployed randomly in WSN. The redundant sensor nodes are effectively identified by the modified LEACH algorithm as per the simulations results. The modified LEACH algorithm puts the redundant sensor nodes in sleep mode, so that the energy consumed by them is also saved. But, it does not provide the solution for the case where the coordinates of a node lie on the demarcation of boundary which separates two neighboring grid cells.

The authors in [5] proposed a quasi-quadratic time distributed algorithm, which is established on a deterministic deployment method, in which the sensor node knows its optimal position even in case of heterogeneous sensing ranges. Quasi-quadratic time is produced and better results are obtained by [5] in comparison to similar algorithms in the literature. Since, duplicate nodes are to be put in sleep mode, they [5] have to introduce a proper scheduling algorithm to identify duplicate nodes in given region of interest and to put them in sleep mode.

In [6], the authors proposed a new technique, which combines energy-efficient cluster head and router selecting protocol (EECRS) for the elimination of redundant sensor nodes. They [6] have considered sensor nodes with different radius (variable radius) for determination of duplicate nodes. The quality of determination of duplicate nodes is guaranteed to 99.9% with less number of on-duty nodes at any given point of time in WSN. After removal of redundancy, each sensor node has more than 8 neighboring sensor nodes. Consumption of energy is reduced considerably using the method proposed by [6] and also lifespan of the WSN is increased by proposed protocol. Since, it removes only duplicate nodes but it suffers from more overlapping of sensors and the coverage of region of interest is not 100%.

The authors in [7] proposed a method which decides the distribution of redundant sensor nodes available around sensor nodes. This method also provides the flexibility to compute position/location for sensor position depending upon application and geographical constraints. But, this method does not eliminate redundancy completely and it does not claim the amount of coverage. In [8], the authors studied the problem of how to detect and eliminate redundancy in a WSN to improve energy efficiency, while preserving the coverage of network. They [8] have used local information to compute Voronoi diagrams for addressing issues related to coverage and redundancy. Localized and distributed algorithms have been proposed by [8] to provide solution for deployment of new sensors and also for addressing failure of sensors. But, this method does not enhance the coverage by eliminating the redundancy.

The authors in [9] investigated the effect of redundancy level on Mean Time to Failure (MTTF) of a cluster based WSN. They derived and evaluated a probability model, which was used to compute system reliability, consumption of energy and appropriate redundancy level which maximizes the network MTTF. They [9] conclude that, MTTF of a system increases as, n, the number of active components per cluster decreases. To achieve a desired level of reliability in WSN, n, number of active components per cluster can be used as a design parameter. However, this suffers from lack of coverage of given region of interest.

In [10], the authors proposed a hybrid technique called "SUBCLUST" to combine clustering and subset formation. It is assumed that coverage area of one sensor overlap's with the coverage area of other sensor during subset formation. The sensor node with least overlapping is added to the subset which the current sensor belongs to. To reduce energy consumption, only one subset of sensor nodes that covers entire network is made active at a time and remaining subset of nodes are made inactive. But, this suffers from lack of coverage of given region of interest.

The authors in [11] redefined the links and WSN topology for detecting redundant sensor nodes using centrality metrics in a Wireless Sensor Network. These sensor nodes are then deactivated. They have used concepts of centrality metrics to reduce the redundancy and to optimize the functionality of WSN. Redundancy reduction is implemented by selecting the WSN elements like sensor nodes or links for reduction randomly on various types of WSN topologies and with varying size of network. This method can be used in a distributed manner for reduction of redundancy in WSN. Since, the WSN elements are chosen randomly for redundancy reduction, the redundancy is not eliminated 100%.

In [12], the authors proposed location aware protocols to eliminate the redundancy while preserving the coverage. If more than one sensor node senses the same region of interest in WSN, a lot of energy will be wasted. This kind of behavior has conflict with one of the requirements of WSN, that is, power efficiency. Hence, they have developed some location aware protocols to eliminate redundancy in WSN. But, this also suffers from more overlapping nodes left in wireless sensor network even after redundancy.

The authors in [13] proposed Area-aware Coverage (A2C), where adjustable sensing and transmission range of sensor nodes are considered and six phases are used to detect and reduce overlapping coverage area. They [13] have minimized the presence of redundant nodes and nodes with minimum coverage in any given area by turning them off. But, the coverage of area is not increased as the size of region of interest increases from $50 \times 50m^2$ to $100 \times 100m^2$.

In [14], the authors consider the nodes which are already deployed in the wireless sensor network and determine redundant nodes. The algorithm proposed by [14] is integrated with clustering routing protocols like DEC, DBEA-LEACH, DB-LEACH, EBCM, and LEACH-E to provide various functions in applications of WSN. The results show that proposed algorithm outperforms original protocols in terms of active number of nodes, full coverage, energy consumption and network lifetime.

A new deterministic algorithm is presented by the authors in [15] for solving coverage problem in wireless sensor networks. The proposed algorithm is able to control the deployment of sensors even presence of obstacles. Redundancy degree is controlled by [15] to provide better coverage with a minimum number of WSN nodes.

The authors in [16] present an omni directional antenna assisted scheme for reducing network redundancy while providing coverage. Redundancy in WSN is achieved by exploiting the directivity of antenna which is outfitted on a sink node. It also maintains connectivity.

In [17], the authors have developed a new algorithm to eliminate the redundancy for data aggregation. The algorithm reduces the energy consumption and increases the life time of Network. But, it does not claim the amount of coverage enhanced after the elimination of redundancy.

3. System Model

Region of Interest to be covered is a Two-Dimensional area for deployment of sensors. The sensor nodes considered for deployment are homogeneous in nature. Sensing range and communication range of all sensors is assumed to be same. The sensors are deployed in a given RoI using random deployment technique. A point in given RoI is said to be covered, if and only if, it falls within the sensing range of atleast one of the sensors deployed. To start with, all the sensor nodes are deployed in given RoI using random deployment method. The RoI is then partitioned into small partitions of equal size. It means, the RoI is partitioned into small grids of equal size. The given RoI contains several such grid points of identical size. Total number of grid points can be obtained by knowing the length and width of the RoI. That is, Total number of grid points is given by Eq. (1)

Total grid points= $length \times width$ (1)

After initial deployment of sensor nodes, they are moved to optimal positions to enhance the coverage using one of the coverage enhancement algorithms [1]. But, movement of sensor nodes to optimal positions results in redundancy, as there are chances that same area in RoI may be covered by more than one sensor node. Hence, it is required to eliminate redundancy while preserving 100% coverage.

The proposed Redundancy Elimination with Coverage Preserving algorithm (RECPA) is used to eliminate the redundancy completely while preserving the coverage.

3.1 Assumptions

The Region of Interest covered by sensor nodes is considered as a plane surface with coordinates (x, y) and sensor node is a disk with center (x, y) and radius r.

1. The type of all sensors considered is same. All these sensors have same sensing range, R_S and communication range, R_C, where ($R_C >= 2R_S$).
2. Sensor node "B" is called as redundant node, if sensor node "A" is located at optimal position and distance between sensor node A and B is less than 25% of sensing range of a sensor A.
3. Each sensor knows its location through Global Positioning System and the Base Station can get the information about the location of each sensor.
4. Each sensor can move to the optimal position, if it is within its radius or sensing range.
5. The proposed algorithm, RECPA, developed by us is executed at Base Station (the centralized architecture). Base station broadcasts the movement plan of each sensor after execution of RECPA.

3.2 Parameters Used

Table 1 lists all the parameters used in the implementation of the proposed algorithm RECPA.

Table 1. Parameters Used

Parameter Used	Description
N	Number of Sensor Nodes Deployed.
Index	Number of Optimal Nodes
S_i	i^{th} Sensor
$Nbrs_i$	Array that stores neighbors of i^{th} sensor
Edst	Euclidian distance
R_S	Sensing Range of Sensor
R_C	Communication Range of Sensor
RoI	Region of Interest
Xopt	Array that stores set of optimal positions related to X-Coordinate
Yopt	Array that stores set of optimal positions related to Y-Coordinate

4. Redundancy Elimination with Coverage Preserving Algorithm.

The Optimal Coverage Enhancement Algorithm[1] deploys the sensor nodes randomly in given RoI, computes the optimal positions, selects the sensor nodes to be moved to optimal position, moves the sensor nodes to optimal positions and finally determines total area covered by all sensors.

Our proposed RECPA uses a set of optimal positions of sensor nodes as the inputs. This method works as follows:

Euclidian distance between the sensor node positioned at optimal position and its neighboring node is determined. If the Euclidian distance is less than 25% of sensing range of a sensor, the neighboring node is considered as redundant node and hence it is eliminated. This is repeated for all the neighboring nodes of each sensor positioned at optimal position. Thus, RECPA eliminates both redundant nodes (Euclidian distance is 0 (zero)) and nodes which provide least coverage of region of interest (Euclidian distance is less than or equal to 25% sensing range of a sensor) while preserving the 100% coverage of RoI in WSN. The RECPA is implemented using MATLAB (R2012a).RECPA works in three phases.

First Phase: It uses a set of optimal positions as inputs, to which, sensor nodes are moved to enhance coverage, after their initial deployment.

Algorithm 1: Deploy Sensor Nodes at Optimal Positions

Function **:** Random Deployment (N, Xopt, Yopt, Index)

1. **for** i = 1 to N **do**
   a. **for** j =1 to Index **do**
      i. Determine Si, which is closest to optimal location with coordinates ($Xopt_j$, $Yopt_j$)
      ii. Move sensor S_i to location ($Xopt_j$, $Yopt_j$)
   b**.end for**
2. **end for**
3. **end function**

Second Phase: The neighboring sensor nodes are determined for each sensor node, S_i(for i=1 to N), located at optimal position,(Xoptj, Yoptj) for j= 1 to Index. It means, for each sensor node, S_i, located at optimal position, (Xoptj, Yoptj) in given region of interest, RoI, determine all the other sensor nodes which are within the sensing range, R_S of S_i.

Algorithm 2: Determine Neighboring Sensor Nodes

Function **:** FINDSN (N, Xopt, Yopt, Index, R_S)

1 .for i =1 to N do
   a. for j = 1 to Index do
      i. if (S_i is positioned at $Xopt_j$,$Yopt_j$) then
         a. Determine the neighbor of S_i, which is within the Sensing Range, R_S of S_i.
         b. Store the neighbor of Si in the array, $Nbrs_i$
      ii. end if
b. end for
2. end for
3. **end function**

Third Phase: In this phase, Euclidian distance, Edst, between sensor node, S_i (for i=1 to N) located at optimal position, ($Xopt_j$, $Yopt_j$) for j= 1 to Index and its neighboring sensor node, S_K is determined.

The sensor node, S_K, is said to be redundant or overlapping node if and only if Euclidian distance, Edst, between the sensor node S_i and its neighbor node, S_K is less than or equal to 25% of sensing range, R_S of Si.

If neighboring sensor node, S_K is within 25% of sensing range of sensor, S_i then S_K is considered as redundant node or overlapping node and it is made inactive by simply turning it off. For instance, if A is the sensor node positioned at optimal position, ($Xopt_j$, $Yopt_j$), B and C are the neighboring sensor nodes of sensor node A with Euclidian distance of 3m and 1.4m respectively from sensor node A then, sensor node C is considered as redundant or overlapping node, because it is within 25% of sensing range 7m (if sensing range of all sensors is 7m) of sensor, A and hence it is eliminated by turning it off. Thus, all the neighboring sensor nodes which are within 25% of sensing range of Sensor, Si for (i=1 to N) are turned off. This procedure is repeated for the all the sensor nodes located at optimal positions. The algorithm3 eliminates all the redundant or overlapping nodes and it is as follows:

Algorithm 3: Eliminate Redundant Sensor Nodes

Function : Remove (N, Nbrs, R_S)

1. **for** i= 1 to N **do**
   a. **for** j=1 to number of neighbors of sensor, S_i **do**
      i. Sensor1= $Nbrs_i$ (j)
      ii. Compute Edst between S_i and Sensor1.
      iii. **if** (Edst is less than 25% of R_S of S_i) **then**
         Consider Sensor1 as redundant node
         Turn off Sensor1.
      iv. end if
   b. end for
2. **end for**
3. **end function**

5. Results and Discussion

5.1 Configuration of Sensor Nodes

Figure 1, Figure 2, Figure 3 and Figure 4 illustrate the configuration of the sensor nodes 20, 30, 40 and 50 respectively, after the movement sensor nodes to optimal positions in RoI [1] using first phase of our proposed RECPA. Size of RoI considered is 50×50 m^2, sensing range, R_S is 7m and the communication range, R_C is 20m.

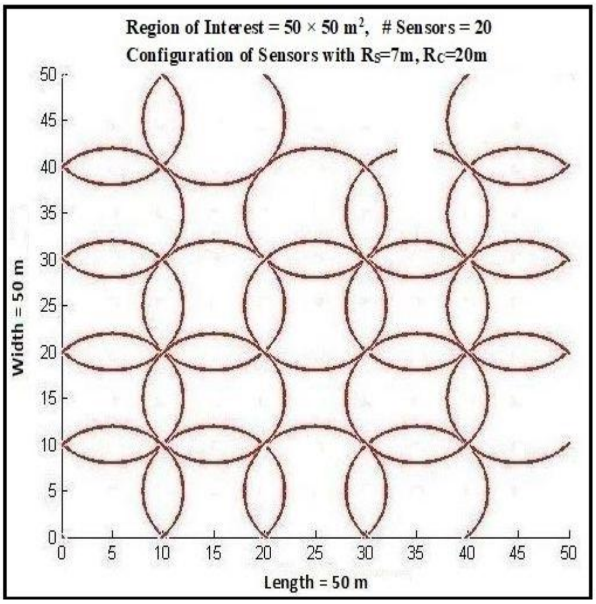

Figure 1. Configuration of 20 Sensor Nodes

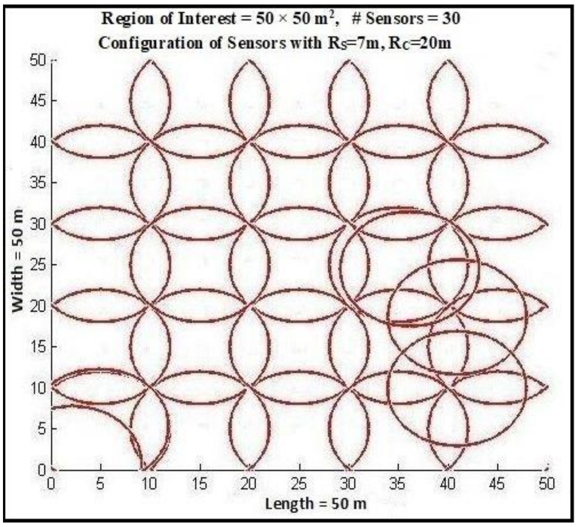

Figure 2. Configuration of 30 Sensor Nodes

From Figure 1, Figure 2, Figure 3 and Figure 4, it is clear that, there are some redundant or overlapping nodes present in the RoI. This redundancy is created after movement of sensor nodes to optimal positions. This is required to be eliminated.

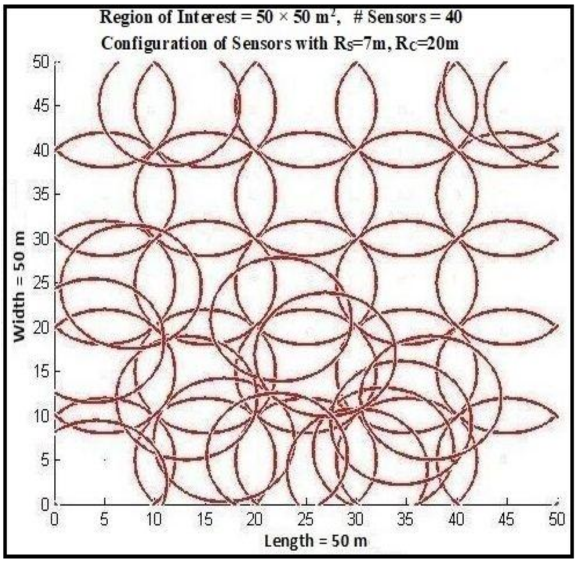

Figure 3. Configuration of 40 Sensor Nodes

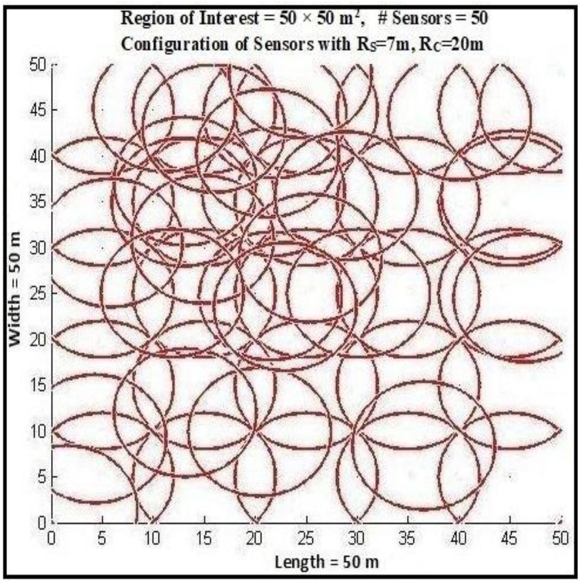

Figure 4. Configuration of 50 Sensor Nodes

5.2 Elimination of Redundancy when RoI=50 ×50 m^2 and R$_S$=7m.

Euclidian distance, Edist, between sensor node, S_i, for i=1 to N, located at optimal position, ($Xopt_j$, $Yopt_j$) for j= 1 to Index and its neighboring sensor node, S_K is determined. If neighboring sensor node, S_K is within 25% of sensing range of sensor, S_i then S_K is considered as redundant or overlapping node and it is made inactive by simply turning it off. Figure 5, Figure 6, Figure 7 and Figure 8 illustrate the final configuration of the sensor nodes 20, 30, 40 and 50 respectively, after eliminating the redundant or overlapping sensor nodes using second and third phase of our proposed algorithm RECPA. Figure 5, Figure 6, Figure 7 and Figure 8 also show that, the coverage of RoI is preserved completely while eliminating the redundant or overlapping sensor nodes. These figures also show that, the optimal number of sensor nodes required for 100% coverage of the given RoI of size 50× 50 m^2 is only 25, when sensing range, R_S=7m and communication range, R_C=20m. Thus, if the number of sensor nodes deployed is above 24, RECPA determines that, after elimination of redundancy, only 25 nodes are required for 100% coverage of RoI of 50×50 m^2 with R_S=7m and R_C =20m.

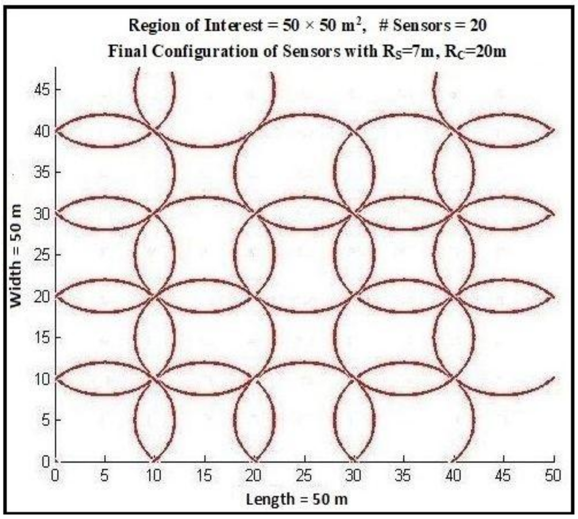

Figure 5. Final Configuration of 20 Nodes

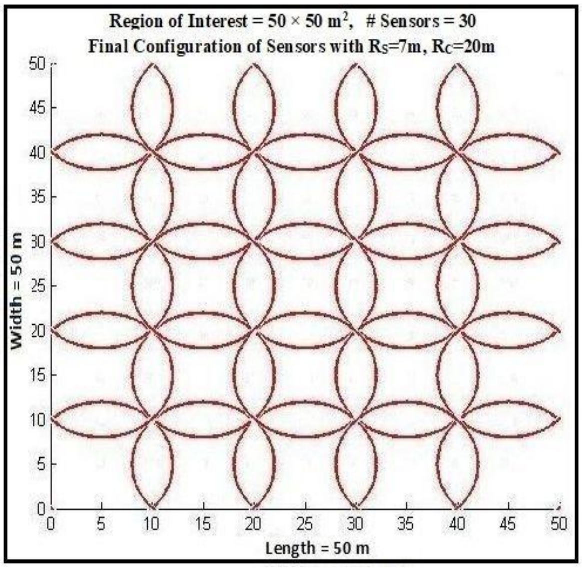

Figure 6. Final Configuration of 30 Nodes

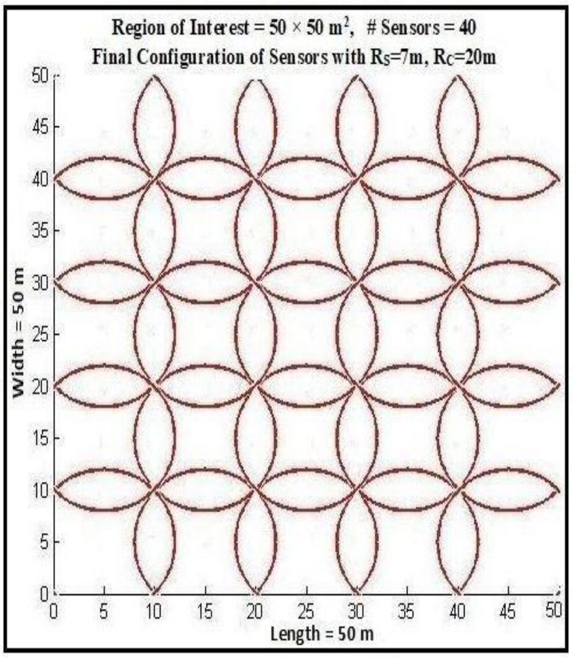

Figure 7. Final Configuration of 40 Nodes

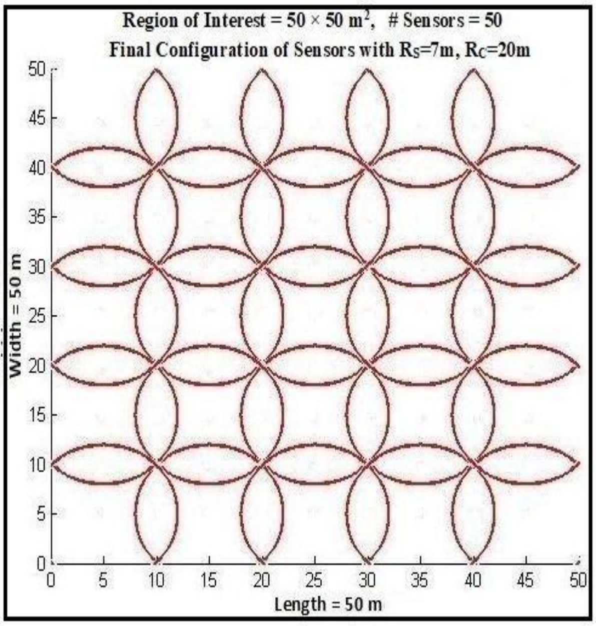

Figure 8. Final Configuration of 50 Nodes

5.3 Variation in Redundant Nodes

Figure 9 shows the comparison of results obtained by RECPA for RoI = 1000 × 1000m^2 and R_S=140m with the results obtained by CPRE [8] forRoI=1000× 1000m^2, and sensing range, R_S=50m.Figure9 shows that the number of redundant or overlapping nodes eliminated increases as the number sensors deployed increases in RECPA in comparison to CPRE [8]. Figure 9 also shows that for the above mentioned parameters, the redundant and overlapping nodes eliminated is 83.3% and 95% when number of sensor nodes deployed is 150 and 500 respectively in RECPA. However, the redundant and overlapping nodes eliminated is 0% and 56% when number of sensor nodes deployed is 150 and 500 respectively in CPRE [8].

Further, the Coverage of RoI is 100% in RECPA, but, coverage of RoI is not claimed in CPRE [8]. This clearly indicates that RECPA yields better results in comparison to CPRE [8].

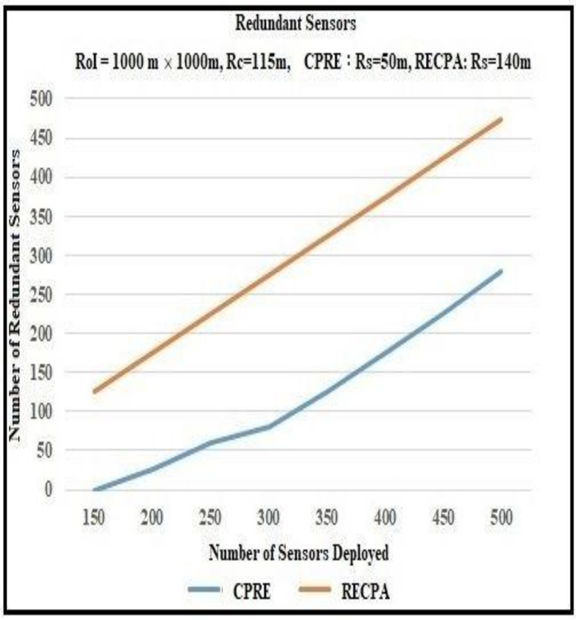

Figure 9. Redundant and Overlapping Nodes with RoI=1000 ×1000m^2

5.4 Coverage of Area with Variation in RoI

Figure 10 shows the comparison of results obtained by RECPA for different size of RoI when R_S=8m with the results obtained by MOC [13]. The Figure 10 shows that coverage of area is 80% in MOC [13], but, coverage of area is 87% in RECPA when RoI is 50 ×50 m^2. Further, coverage of area is 58% in MOC [13] and coverage of area is 80% in RECPA when RoI is 100 × 100m^2. It is clear from Figure 10 that, the coverage of area decreases as the RoI increases from 50 ×50m^2 to 100 × 100m^{2}in both MOC [13] and RECPA. This is because, the sensing range remains same (R_S=8m) from RoI of 50 ×50 m^{2}to 100 × 100m^2. But, for all different size of RoI, the coverage of area provided is better in RECPA in comparison to MOC[13].This clearly indicates that RECPA yields better results than MOC [13] for all different size of RoI when Rs=8m.

The number of initial sensor nodes deployed for varying size of RoI is as follows: 18 nodes for 50 × 50 m^2, 25 nodes for 60 × 60m^2, 35 nodes for 70 × 70 m^2, 46 nodes for 80 × 80 m^2,60 nodes for 90 × 90 m^2 and 74 nodes for 100×100m^2.

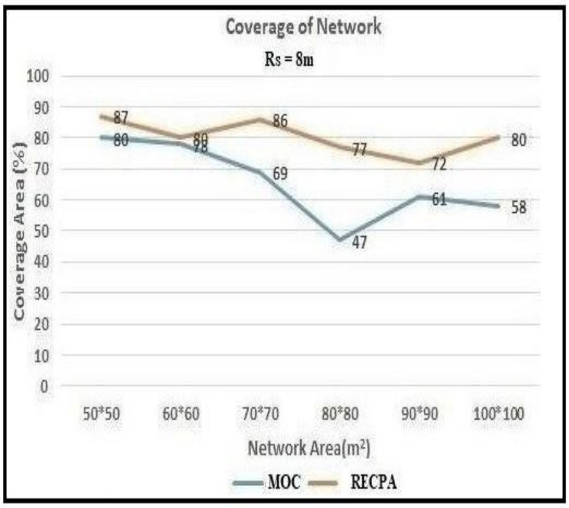

Figure 10. Coverage with Variation in Region of Interest (RoI) or Network Area (m^2)

5.5 Redundant and Overlapping Nodes for RoI = 50 × 50m^2

Figure 11 illustrates the number of sensor nodes deployed vs. number of nodes moved to optimal positions from their original positions, where, they were deployed randomly in RoI of 50× 50 m^2 with R_S = 7m and R_C = 20m.The nodes which are moved to optimal positions are called optimal nodes or dynamic nodes. Figure11 also shows the number of redundant and overlapping nodes which are not moved to optimal positions. Since, the redundant and overlapping nodes are not moved, they are made inactive by putting them in sleep mode or by turning off them. In Figure 11, the percentage of redundant and overlapping nodes identified and eliminated is 17% when number of nodes deployed is 30 and percentage of redundant nodes identified and eliminated is 50% when number of nodes deployed is 50. Thus, it is clear that the number of optimal nodes (dynamic nodes) required to cover RoI of 50× 50 m^2 is only 25, when number of sensors deployed is above 24.Since, optimal number of nodes required to obtain 100% coverage of RoI is reduced considerably and the redundant and overlapping nodes are made inactive by putting them in sleep mode or by turning off them, the amount of energy consumed is also reduced significantly.

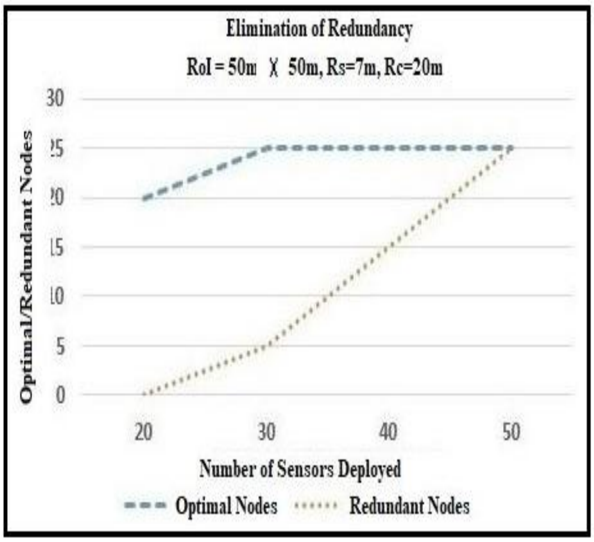

Figure 11. Redundant and Optimal Sensor Nodes

6. Conclusions

The percentage of redundant and overlapping nodes eliminated is much higher in RECPA in comparison to CPRE [8] when number of nodes deployed is between 150 and 500. Also, RECPA preserves 100% coverage of RoI while eliminating redundancy. However, CPRE [8] does not claim any coverage of RoI after elimination of redundancy.

Further, the coverage of area is better in RECPA in comparison to MOC [13] as the RoI increases from 50 ×50m^2 to 100 ×100m^2. Thus, RECPA yields better results than MOC [13] for all different size of RoI when Rs=8m.

It was also illustrated that the number of optimal nodes (dynamic nodes) required to cover RoI of 50 × 50 m^{2}with R_S=7m is only 25, when number of sensors deployed is above 24.

It can also be concluded from the results that, higher the sensing Range R_S, larger the coverage of RoI and number of optimal nodes required to provide complete coverage will be very less. This also indicates that, more number of redundant and overlapping nodes will be reduced by the proposed method. Since, RECPA eliminates redundant nodes and even the nodes which provide least coverage of region of interest, it significantly reduces the optimal number of nodes required to provide 100% coverage of given region of interest.

Thus, RECPA provides 100% coverage of given region of interest of any size with very less number of optimal nodes. Hence, RECPA serves better than the other methods available in literature.

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