International Journal of Engineering & Technology, 7 (4) (2018) 4468-4474

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 18951
Research paper

A three phase hybrid approach for enhancement of coverage in wireless sensor network

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Abstract

In Wireless Sensor Network, when sensor nodes are deployed using random deployment method, the given area of interest may not be covered completely and coverage holes may also exist. But, coverage of region of interest can be enhanced by moving sensors to optimal positions. In this paper, a three phase hybrid approach for enhancement of coverage is proposed and implemented. In first phase, sensor nodes are deployed at random positions in the given region of interest. In second phase, a heuristic function is used to determine the optimal positions based on the Euclidian distance between any two optimal positions. In third phase, only the nodes which are close to the optimal positions are chosen and moved. But, rest of the nodes are not moved. They remain at same position, where they were deployed in first stage. Since, some are static and some are moved, this approach is termed as Hybrid approach. Simulation results are presented with different number of sensor nodes and different size of region of interest. The proposed new algorithm performs better in terms of coverage of region of interest, number of movements, average distance moved and number of rounds required to converge than the other coverage enhancement algorithms.

Keywords: *Coverage; Deterministic; Random Deployment; Sensor Nodes; Wireless Sensor Networks.*

1. Introduction

Wireless Sensor Network (WSN) has got more focus in the recent years, as it is used in most of the important applications like disaster monitoring [1], forest fire detection [2], healthcare, military [3], environmental monitoring and in many other applications. In WSN, sensor nodes can be deployed using random deployment method or deterministic deployment method. There are some applications like natural disaster area, harsh environments and toxic areas, where, sensor nodes cannot be deployed using deterministic deployment method. However, in these cases, random deployment can be used to deploy sensor nodes. In deterministic deployment, the Region of Interest (RoI) can be covered completely as the optimal locations of sensor nodes are known in advance.

But, in case of random deployment method, the sensor nodes are deployed using aircraft or some other way randomly in Region of Interest (RoI), in which, the optimal positions of sensor nodes are not known prior to random deployment [4]. Since, initial location of sensors are not uniform, after random deployment, few places are covered with more sensor nodes and few other places are covered with less sensor nodes. This results in coverage hole in region of interest. Thus, the sensor nodes do not cover the RoI completely.

Coverage of area has other issues such as the amount of area covered in given region of interest in WSN (without coverage holes), number of movements required to cover the given region of interest, average distance moved by all the sensor nodes that are moved to optimal positions, number of rounds required for converging the algorithm and finally the number of optimal nodes required to cover the given region of interest completely in addition to elimination of coverage holes.

To solve above coverage problems or issues, many coverage enhancement algorithms are used [13], [14] and [24]. These coverage enhancement algorithms deploy the sensor nodes randomly first and then determine the optimal positions for improving the coverage. Then, the selected sensor nodes are moved to the optimal locations [14]. The results obtained by [13], [14] and [24] show that, area covered is less, average distance moved by sensors is more, number of movements required to obtain the better coverage is more and number of rounds required for convergence of the algorithm is high. Hence, it shows that, still there is a scope for further enhancement of coverage of RoI to address the above mentioned issues. Since, most of the issues of coverage are not addressed completely in the past, there is a requirement for development of an optimal approach for addressing all the above issues.

A Three Phase Hybrid Approach is developed for Enhancement of Coverage (HAEC) in WSN to enhance the coverage of given region of interest in WSN. The first phase deploys the sensor nodes randomly in given region of interest. Second phase uses a heuristic function to determine the optimal positions for moving the sensor nodes from their original deployment positions. The optimal positions are decided in such a way that, the Euclidian distance between any two optimal positions should be more than the sensing range and should be less than twice the sensing range of a sensor.

Third phase chooses the sensor nodes which are close to the optimal positions and moves them to the optimal positions to improve the coverage. The nodes which are not close to the optimal positions are retained at the same positions, where, they were deployed in the first phase. This kind of nodes are termed as static nodes and the nodes which are moved to the optimal positions are termed as dynamic nodes. Hence, the proposed three phase HAEC uses combination of both static and dynamic nodes to enhance the coverage.

Paper is organized as follows. In Section 2, related works are discussed. Section 3 presents the system model used and Section 4 presents the proposed algorithm. In Section 5, the results are presented and conclusions are drawn in Section 6.

2. Related work

The significant work carried out on random sensor node deployment and coverage related problems by researchers is discussed in this section. A new approach to enhance coverage using Voronoi diagram is proposed in [4], where, region of interest is divided into cells and genetic algorithm is used to determine optimal places for placing additional mobile nodes to eliminate coverage holes. But, it does not provide full coverage. A V-VABC algorithm has been proposed in [5] for enhancement of coverage in WSN. But, it does not provide 100% coverage. Sensor nodes are moved to discrete targets with minimal movements as presented in [6] for improving the coverage, But, this method does not provide the complete coverage. A distributed coverage hole detection scheme is proposed in [7] to detect presence of coverage holes using the information about their one hop neighbors without taking help of sink. But, this scheme does not provide full coverage.

A new immune node deployment algorithm is proposed in [8] for mobile wireless sensor network to enhance the coverage of network area. After initial configuration, this algorithm redeploys the mobile sensor nodes provided coverage is enhanced and energy required for movement of nodes is reduced. But, it does not provide complete coverage of area. A genetic algorithm- (GA) based sensor deployment strategy is presented in [9] for maximizing network coverage, and performance of strategy was measured with random node deployment. But this algorithm fails in providing complete coverage of area. Various recent approaches used for providing coverage of WSNs using Voronoi Diagram are presented in [10]. But, none of the approaches provides 100% coverage of network area.

Two grid-based algorithms Grid Square Coverage version-1 and Grid Square Coverage version-2 for addressing the problems of coverage of WSN are presented in [11]. But, they do not provide full coverage. Grid square coverage version-1 algorithm provides 78% of coverage and Grid square coverage version-2 provides 73% of coverage. Strategies proposed in [12] avoid undesirable network configurations. But, none of these strategies provide 100% coverage. Further, these strategies do not reduce the average distance moved significantly and number of movements required to achieve complete coverage is also more. Sensor nodes are grouped dynamically for adjusting the coverage area by Multi-Targets Coverage Protocol with Associate Attributes (MTCPAA) algorithm which is presented in [13]. This scheme uses greedy algorithm for optimizing coverage area and also to enhance the network lifetime. But, the amount of coverage is not complete and distance moved is more.

Differential evolution algorithm for enhancing coverage in two phases is presented in [14] to compute target positions for sensor nodes in first phase and the sensor nodes to be moved to target positions are identified and moved in second phase. But, the total distance moved by all the sensors after second phase is very high.

An Efficient Self-deployment Algorithm (ESA) has been presented in [15] for improving coverage. In this method, mobile sensors can move and organize themselves at best target positions. But, the average distance moved by all the sensors nodes is quite high. A sensor deployment or relocation plan for providing full coverage is presented in [16]. In this method, some sensors are moved and some are retained at same positions. But, this method does not reduce the total distance moved by all the sensor nodes. A node optimal coverage strategy based on improved genetic algorithm and binary ant colony algorithm is presented in [17]. But, this method does not provide full coverage and distance moved by the sensors is also quite high. An approach to address the placement problem of sensors in WSN is proposed in [18]. It provides better coverage and connectivity. However, the distance moved by al sensors is very high. A method to deploy clustered heads in grouped industrial mobile wireless networks is proposed in [19]. But, average distance moved by all the sensor nodes is high. An optimized strategy coverage control (OSCC) based on geometric figure, related theories, probability theory and converge property is proposed in [20]. It uses less number of nodes to provide better coverage. However, distance moved is very high. Comparison of algorithms used for enhancement of coverage and for reducing number of movements of sensor nodes is presented in [21].

An approach based on the "Markov process" has been presented to improve coverage in [22]. But, distance moved by all the sensors is high and number of movements for providing desired coverage is also more. A modified discrete binary particle swarm optimization for providing better coverage of area is presented in [23].This method provides better coverage. But, the distance moved and number of movements produced by sensor nodes is more. An Edge Based Centroid (EBC) algorithm has been presented in [24] for enhancement of area coverage with quicker convergence rate in WSN. It provides coverage up to 97%. But, still there is a scope for enhancement of coverage area. But, Number of rounds taken to converge the algorithm is high.

3. System model

A 2-Dimensional area is considered as the region of interest (RoI) for the random deployment of sensors. All the sensors are homogeneous with same sensing and communication range [5], [24]. These sensors are deployed randomly in given RoI. Any point in RoI is covered, if and only if, it appears within radius/sensing range of at least one sensor. Initially, sensor nodes are deployed randomly using random deployment technique in given RoI, then RoI is divided into small grids of same size. The given RoI consists of a several grid points and total number of grid points is computed by length × width. The proposed three phase Hybrid Approach for Enhancement of Coverage (HAEC) determines optimal positions, which the, sensors should move to, after their initial deployment, then identifies the sensor nodes which are very close to optimal positions and finally moves these sensor nodes to the optimal positions. The three phase HAEC is used to determine the amount of area covered by sensors, average distance moved by all sensors, number of movements and number of rounds required to get better coverage. The area covered by sensors can be computed as ratio of number of grid points covered by sensors after their movement to optimal positions to total number of grid points in RoI. The three phase HAEC is implemented using MATLAB (R2012a).

3.1. Assumptions

- All sensors are of homogeneous type and have same sensing range, R_S and communication range, $R_C >= 2R_S$.
- All the sensors know their location through Global Positioning System (GPS), and information about location of each sensor can be sent to the base station (BS).
- Each sensor is able to move to the optimal position which is within its sensing range, R_S.
- The algorithm developed by us is implemented in a centralized architecture and Base Station executes the algorithm and broadcasts the sensor movement plan to all sensors in network.

3.2. Parameters used

List of parameters/Symbols used in this paper is listed in Table 1.

Table 1: Parameters Used

Parameter Used	Meaning
Length	Length of Two-Dimensional Area
Width	Width of 2-Dimensional Area
R_S	Sensing Range of Sensor
R_C	Communication Range of Sensor
N	Total Number of Sensor Nodes
S	Set of Sensor Nodes

Si	Sensor i
const	Constant to multiply the random numbers generated for x and y coordinates
RoI	Region of Interest (Length × Width)
xrand	Array of random numbers for X coordinates of Sensors
yrand	Array of random numbers for Y coordinates of Sensors
optimal	Array storing the optimal positions for movement of sensor nodes
index	No. of optimal positions

4. Hybrid approach for enhancement of coverage in WSN

The proposed three phase Hybrid Approach for Enhancement of Coverage (HAEC) is discussed below.
First Phase of Algorithm: The sensor nodes are deployed randomly in given RoI. Random numbers are generated between lower=0 and upper=1 for N sensors to be deployed using (1) and (2).

$$xrand = lower + (upper - lower) \times rand(N,1) \quad (1)$$

$$yrand = lower + (upper - lower) \times rand(N,1) \quad (2)$$

The Xi and Yi (for i = 1 to N Sensors) coordinates are computed using (3) and (4) for the sensor i (for i = 1 to N). The term const is the constant which is used to multiply the random numbers generated for coordinates. The value of const is dependent upon the size of the RoI and it is set to Length or Width of the RoI. Algorithm-1 presents the deployment of sensor nodes randomly in RoI.

$$Xi = xrand(i) \times const \text{ for i=0 to N} \quad (3)$$

$$Yi = yrand(i) \times const \text{ for i=0 to N} \quad (4)$$

Algorithm 1: Deploy Sensor Nodes Randomly
1) Generate N Random Numbers for X and Y coordinates using (1) and (2) respectively.
2) Deploy Sensor Si at Location (Xi, Yi) for i= 1 to N

Second Phase of Algorithm: Algorithm 2 generates first optimal position, called opt, randomly and stores it in array, optimal. The remaining optimal positions are generated with reference to first optimal position, opt. It should be noted that, the Euclidian distance, Edist, between any two optimal positions should be R_S <= Edist <= $2R_S$. All the optimal positions generated are stored in array, optimal, as shown in Algorithm 2.

Algorithm 2: Determine the Optimal Positions
1) Initially, generate first optimal position randomly, op1
2) Store op1 in optimal array, optimal
3) While (true) do
   a) Set accept1 and accept2 to 0.
   b) While (accept1 and accept2) do
      i) Generate next position, opnext and set accept-1 to 1, if it is within RoI.
      ii) For i = 1 to length of optimal array, optimal
         a) Compute Euclidian distance between opnext and optimali,
         b) If Euclidian distance is between RS and 2 RS, set accept2 to 1.
         c)If both accept-1 and accept-2 are 1, insert opnext into optimal array, optimal
         d)Determine and remove duplicate optimal positions if any i the array optimal.
         e)if (no more optimal positions are to be generated) then break.

Third Phase of Algorithm: Algorithm 3 and Algorithm 4 are designed to implement third phase. The nodes which are closer to the optimal positions are determined in Algorithm 3 and The Euclidian distance between the Sensor Si (for i = 1 to N) and the optimal position, optimal (j) (for j=1 to index) is computed using (5).

$$Edist = \sqrt{(Xi - Xj)^2 + (Yi - Yj)^2} \quad (5)$$

Where, Xi and Yi (for i=1 to N) are the coordinates of the Sensor Si after the initial deployment at random position in RoI and Xj and Yj (for j=1 to index) are the coordinates of the optimal position, optimal (j). If the Euclidian distance, Edist, between the sensor Si and the optimal(j) is less than or equal to sensing range of Sensor Si, the optimal(j) is considered as the closer location (optimal position) to sensor Si.

Algorithm 3: Find Sensors close to optimal positions
for i = 1 to Number of sensor nodes do
  for j = 1 to number of optimal positions do
   a) Compute Euclidian distance between Sensor, Si and optimal position, optimal (j) using (5)
   b) if (Euclidian distance is less than or equal to Sensing range) then Consider optimal (j), as closer location to Sensor, Si

The Algorithm 4 is used to choose the closest node Si amongst a set of nodes which are closer to the optimal position, optimal (j) determined in Algorithm 3. A Node Si is closer to the optimal position, optimal (j), if and only if, optimal (j) is located within the sensing range of Si. For instance, assume that sensing range is 7m and if the sensor nodes S1, S2 and S3 are at a distance of 2m, 3m and 4m respectively from the optimal position, optimal (j), the sensor node S1 is chosen for moving to the optimal (j) position, as it is the closest node to optimal (j). The sensors S2 and S3 will be retained at same location. Thus, if the sensor node Si is chosen for moving to the optimal position, optimal (j), the coordinates of sensor Si are set to the coordinates of the optimal (j) and the node Si is then moved to the optimal position, optimal (j). The nodes which are not closer to any of the optimal positions are just retained at same positions, where they were deployed in phase one. Such nodes are called static nodes and the nodes which are chosen for movement to optimal positions are called dynamic nodes. Since both static and dynamic nodes are considered for enhancement of coverage, this method is termed as hybrid approach for enhancement of coverage in WSN. The Algorithm 4 also computes the total distance moved by each sensor and number of movements caused due to movement of sensors to optimal positions.

Algorithm 4: Move-Sensors-to-Optimal-Position
for i = 1 to Number of Sensor nodes do
 i) for j = 1 to number of optimal positions do
    Find the Sensor node, Si, which is closest to one of the optimal positions, optimal (j), which is unfilled.
 ii) Determine distance moved by Si and add it to total distance moved.
 iii) Move Sensor, Si to optimal (j) position.
 iv) Set optimal position, optimal (j) as filled one.
 v) Determine number of movements taken by Sensor, Si to reach optimal position, optimal (j).

5. Results and discussion

5.1. Initial deployment of nodes

Initial random deployment of sensor nodes 20, 30, 40 and 50 is depicted in Figure 1, Figure 2, Figure 3 and Figure 4 respectively using Algorithm 1 of HAEC. Size of RoI considered is 50m × 50m, sensing range, R_S is 7m and communication range, R_C is 20m. These figures show that few places are covered with more sensor nodes and few other places are covered with less sensor nodes after initial deployment. So, the sensor nodes may not cover the RoI completely due to random deployment. These figures also show the existence of coverage holes.

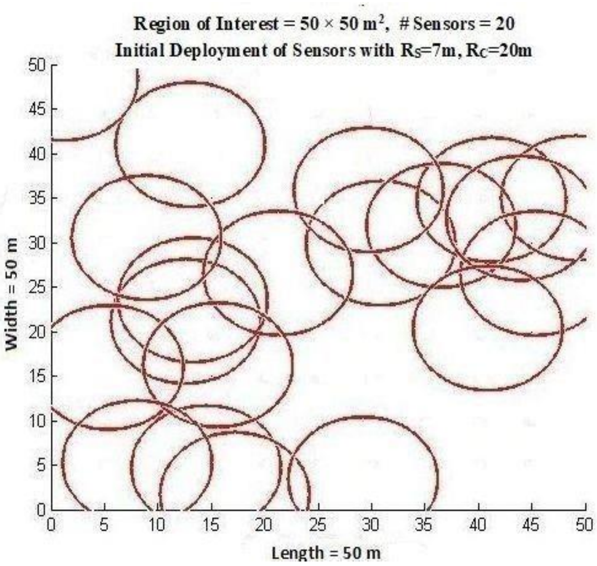

Fig. 1: Initial Deployment of 20 Sensor Nodes.

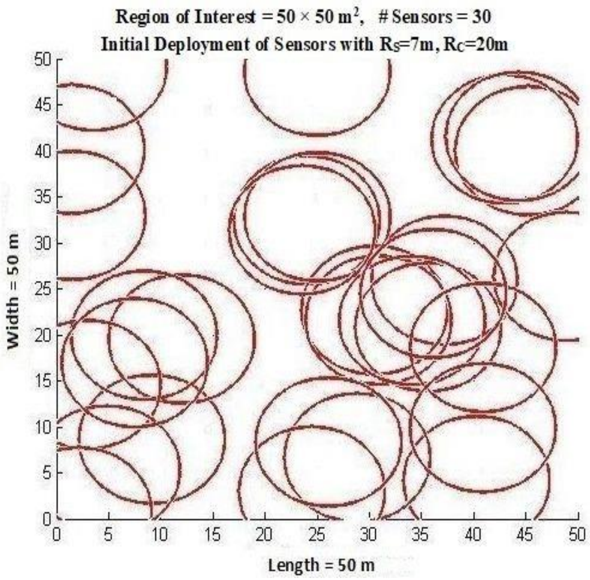

Fig. 2: Initial Deployment of 30 Sensor Nodes.

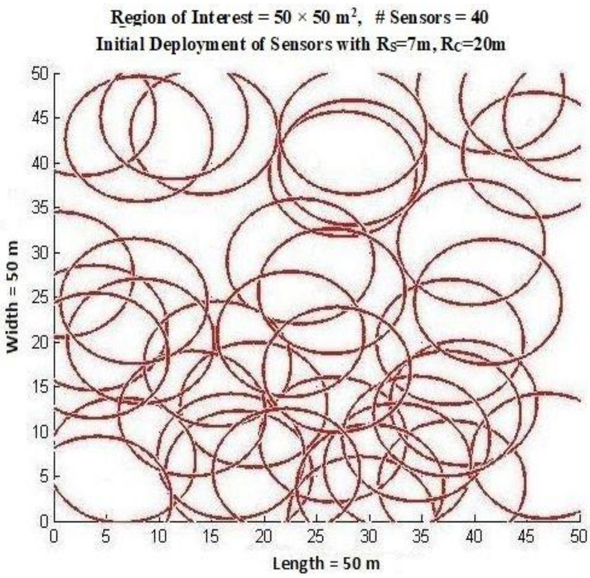

Fig. 3: Initial Deployment of 40 Sensor Nodes.

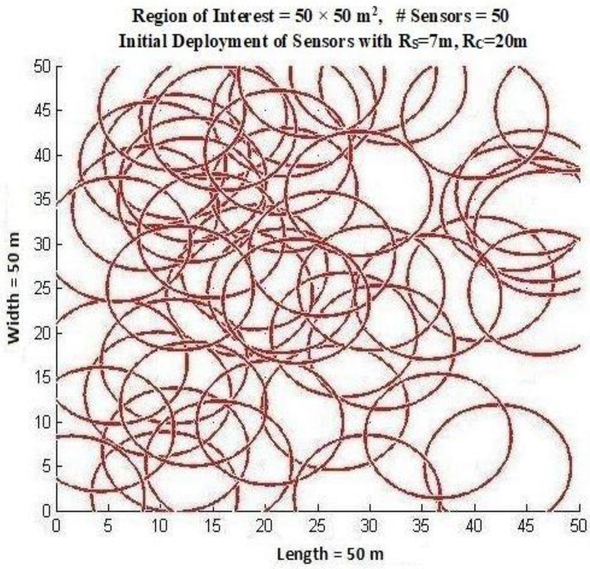

Fig. 4: Initial Deployment of 50 Sensor Nodes.

5.2. Configuration of sensors

Optimal positions are determined using second phase of HAEC for enhancement of coverage. Configuration of sensor nodes 20,30,40 and 50 after they are moved to optimal positions in RoI using 3rd and 4th phase of HAEC algorithm is depicted in Figure 5, Figure 6, Figure 7 and Figure 8 respectively. Size of RoI considered is 50 × 50 m^2, sensing range, R_S is 7m and communication range, R_C is 20m. Optimal position which is closest to each sensor node is determined and sensor node is moved to that location. Thus, all the sensor nodes are moved to closest optimal positions after their initial deployment. Hence, after movement of sensor nodes to their closest optimal position, the Euclidian distance between any two nodes is $R_S <= Edist <= 2\ R_S$. But, Movement of sensor nodes to optimal positions may lead to overlapping of nodes. It means, the Euclidian distance between any two sensor nodes may be less than the sensing range of sensor. The figures, Figure 5, Figure 6, Figure 7 and Figure 8 show that there are no coverage holes in RoI.

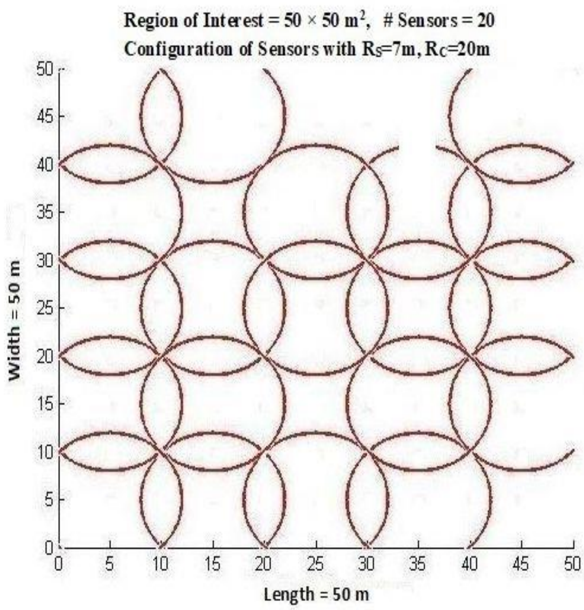

Fig. 5: Configuration of 20 Sensor Nodes.

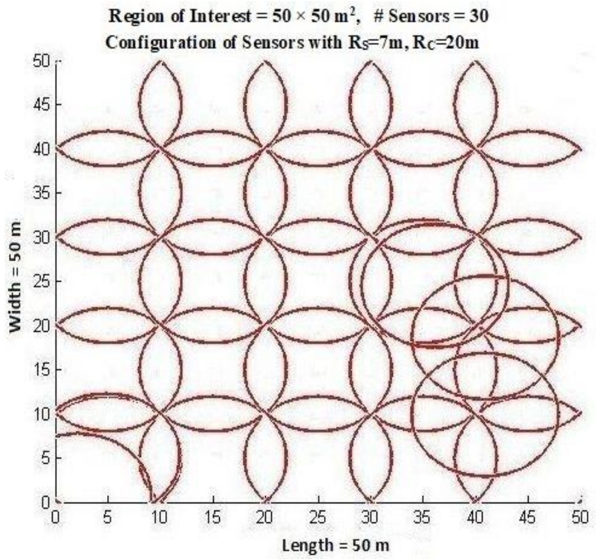

Fig. 6: Configuration of 30 Sensor Nodes.

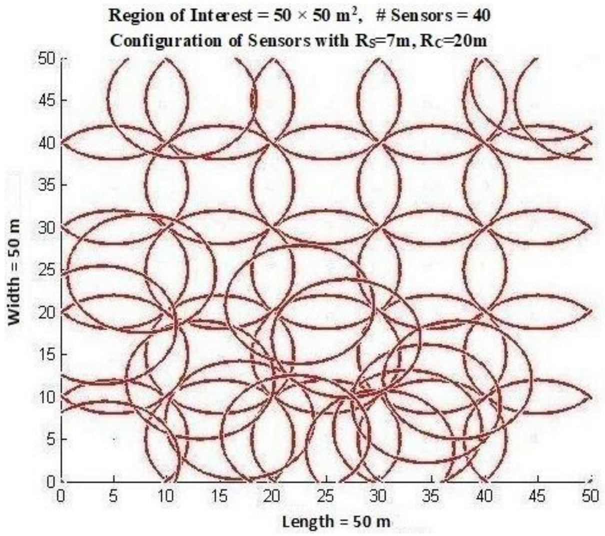

Fig. 7: Configuration of 40 Sensor Nodes.

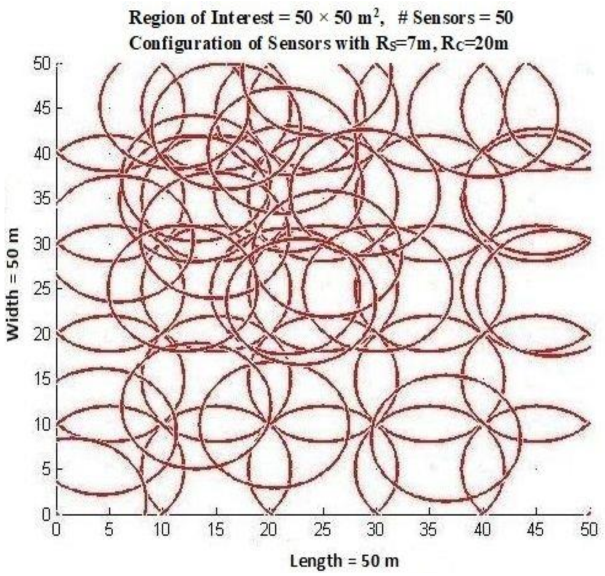

Fig. 8: Configuration of 50 Sensor Nodes.

5.3. Comparison of results of coverage algorithms

In this section, the results obtained by HAEC have been compared with the results obtained by the existing coverage algorithms, considering the RoI as 50 × 50 m^2, sensing range, Rs as 7m and communication range, R_C as 20m. Figure 9 presents the comparison of results. Figure 9 shows that, when the number of sensors is 20, coverage of VEC is 85% [12] and coverage of HAEC is only 80%. However, when number of sensors is increased from 20 to 30, the coverage of HAEC is 100% and coverage of EBC is 91% [24]. When number of sensors is 40, coverage of HAEC is 100% and coverage of EBC is 96% [24] and when number of sensors is 50, coverage of HAEC is 100% and the coverage of EBC is 97% [24]. Thus, when the number of sensors is 20, VEC performs better than HAEC and when the number of sensors is above 20, HAEC performs better than all other coverage algorithms as shown in Figure 9.

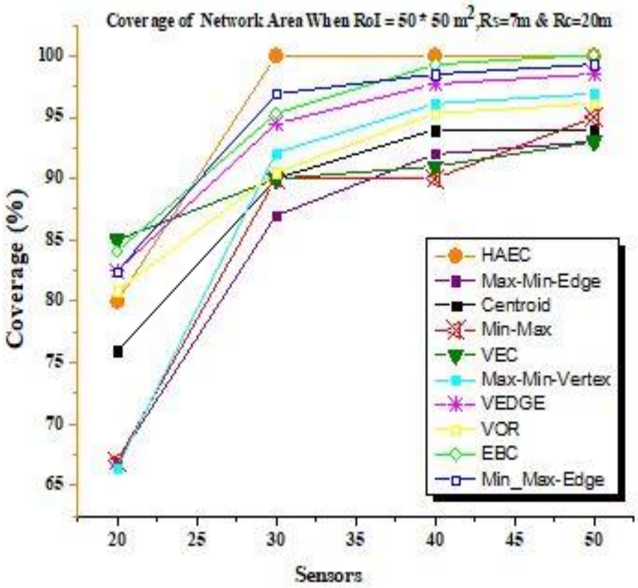

Fig. 9: Comparison of Results of Different Coverage Algorithms.

5.4. Average distance moved

Average distance moved by sensors after they are moved to optimal positions is shown in Figure 10. Figure 10 shows that, average distance moved by the sensors in HAEC is low compared to all the other algorithms [12], when number of nodes deployed is between 20 and 50. This is because, very less number of nodes which are very close to optimal positions are selected and moved to the optimal positions and remaining sensors are retained at same location in HAEC. Thus, average distance moved by the sensors is low in HAEC in comparison to other algorithms [12].

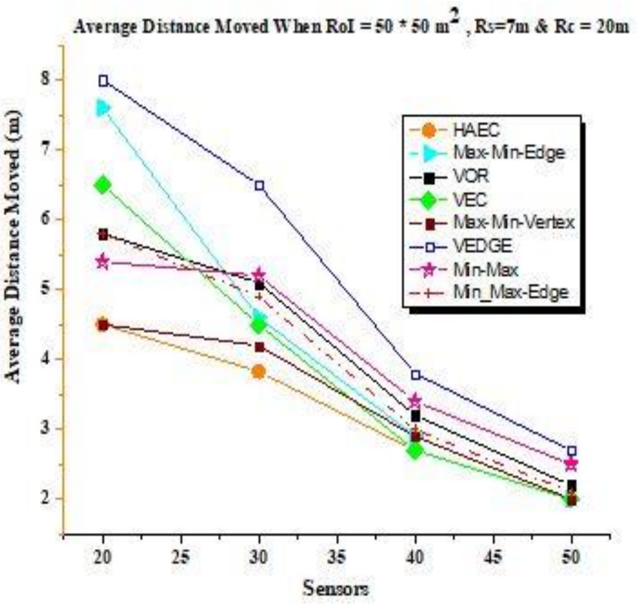

Fig. 10: Average Distance Moved by All Sensors.

5.5. Number of movements

Figure 11 depicts the number of movements caused by sensors after they are moved to optimal positions from initial deployment positions. Figure 11 shows that number of movements caused by HAEC is 5 and number of movements caused by VEC [12] is 7 when number of nodes deployed is 20. Further, number of movements caused by both HAEC and VEC is 2 when number of sensors deployed is 50. This indicates that, HAEC performs better in comparison to other similar algorithms and also number of movements caused is low compared to average number of movements [12].

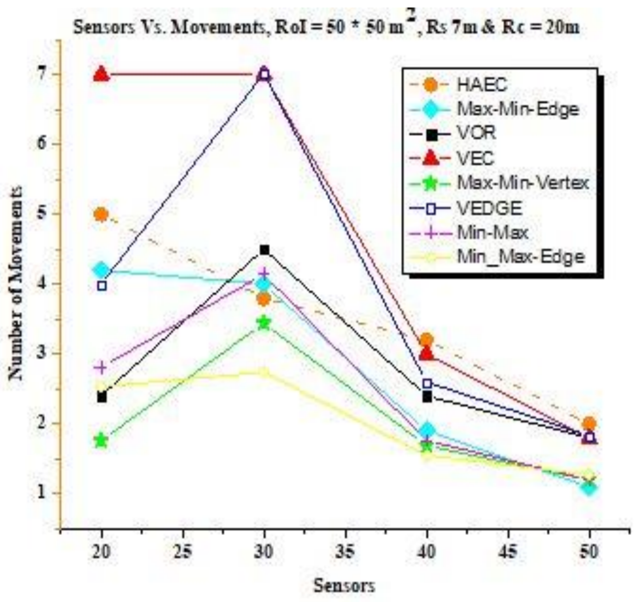

Fig. 11: Number of Movements.

5.6. Number of rounds

Figure 12 depicts the number of rounds taken by HAEC to converge for achieving 100% coverage of given RoI in WSN. Figure 12 shows that HAEC takes 3 rounds to achieve 80% coverage and EBC [24] also takes 3 rounds to achieve 77% coverage when number of nodes deployed is 20. HAEC takes only 2 rounds to achieve 100% coverage, whereas, EBC takes 5 rounds to achieve 90% coverage when number of nodes deployed is 30. Further, the number of rounds taken by both HAEC and EBC is almost remain same when number of nodes deployed is above 40. Thus, HAEC performs better than other similar algorithms [24] with respect the convergence of the algorithm.

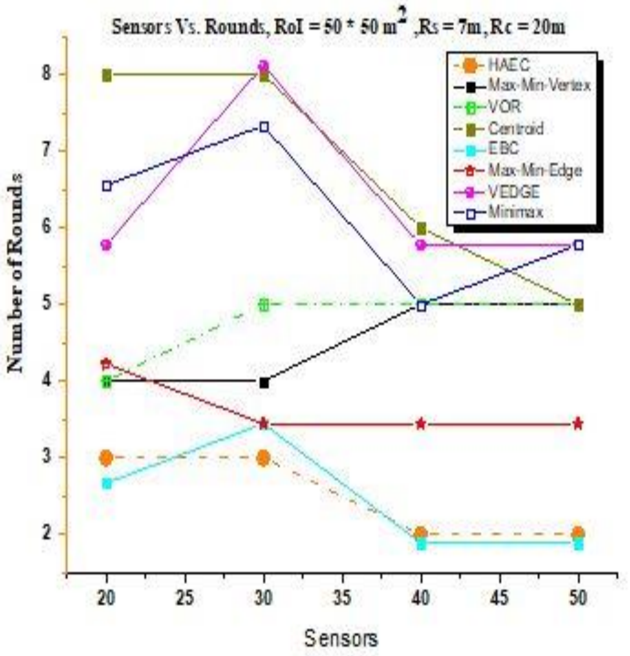

Fig. 12: Number of Rounds.

5.7. Optimal sensing range for varying size of RoI

Optimal sensing range required to provide 100% coverage for varying size of RoI is computed through experimental results using MATLAB (R12a). Figure 13 shows the optimal sensing range computed to provide varying size of RoI. The experiment was run 50 times and average results are presented in the Figure 13. The Figure 13 shows that for RoI of 50m × 50m, the optimal sensing range is 7m and for RoI of size 500m × 500m, the optimal sensing range is 70m to provide 100% coverage of RoI. From the Figure 13, it is clear that, as the size of RoI increases, the optimal sensing range increases linearly. From experimental results, following relationship can be obtained between sensing range Rs and width /Length of RoI (If RoI is square).

$Rs = 0.14 * Length$ of RoI.

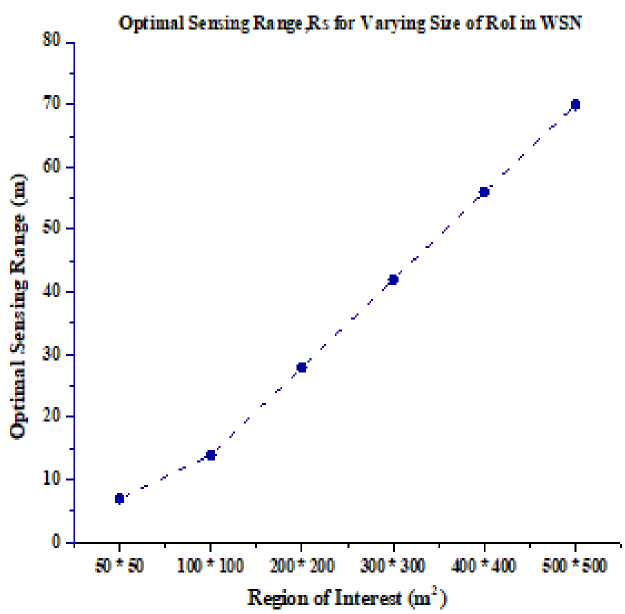

Fig. 13: Optimal Sensing Range for Varying Size of RoI.

6. Conclusion

The proposed three phase Hybrid Approach for Enhancement of Coverage (HAEC) enhances the coverage of area, reduces the average distance moved by all the sensors, decreases the number of movements caused by sensors to move to optimal locations and converges in less number of rounds in given region of interest (RoI). In this approach, the nodes which are closest to the optimal positions are selected and are moved to their respective optimal positions after their initial random deployment, provided the area of coverage increases after their movement. Otherwise, they are not moved. Coverage of sensing field increases as number of sensor nodes increases. The results show that, HAEC provides 100% coverage of RoI when number of nodes deployed is above 25. It also shows that, minimum number of sensor nodes required for 100% coverage of RoI is only 30 and the area of coverage remains constant (100%) between 30 and 50 sensor nodes.
Further, average distance moved and number of movements and number of rounds caused is low in HAEC as compared to other similar algorithms. Thus, the HAEC algorithm outperforms the existing methods with respect to area coverage, average distance moved and number of movements and number of rounds required for algorithm to converge. Finally, we have presented the optimal sensing range required to provide 100% coverage for varying size of RoI through experimental results using MATLAB (R12a). It is proved that, as the size of RoI increases, the optimal sensing range, R_S also increases. Hence, sensing range is directly proportional to region of interest.

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