Energy Efficient Node Deployment Technique for Heterogeneous Wireless Sensor Network based Object Detection

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***Abstract*—Lifetime of the network and the quality of operation are the two important issues in a wireless sensor network system meant for object detection and tracking application. At the same time, there should be a tradeoff between network cost and the quality of operation as high cost of the network limits its real-time usability. Heterogeneous wireless sensor networks promises the prolonged network lifetime as well as enhances network reliability as they contain a mixture of nodes with different characteristics. Further prolongation of network lifetime can be achieved by managing the available node energy in a proper way, i.e, by minimizing number of communication, minimizing node density, minimizing overhead information generated during operation etc. Proper node deployment scheme not only helps to enhance the lifetime of the network but also helps in reducing deployment cost while maintaining the quality of operation in terms of object detection accuracy. This paper focuses on the energy efficient node deployment in heterogeneous wireless sensor network system with the features of maximum network coverage, optimum node density and optimum network cost. This paper proposes a novel energy efficient node deployment algorithm that determines the number of static and mobile nodes required for deployment and then relocates the mobile nodes to cover up the coverage hole using 8-neighbourhood and Particle Swarm Optimization (PSO) algorithm. The performance of the proposed algorithm is compared with corresponding model of Harmony Search Algorithm (HSA) and PSO based node deployment and it is seen that the proposed model outperforms better in comparison to them**.

Keywords—Heterogeneous wireless sensor network; energy efficiency; node deployment; object detection network; particle swarm optimization; harmony search algorithm

I. Introduction

Wireless Sensor Network (WSN) is a network of tiny connected sensors deployed in different fields like surveillance system, disaster management, wildlife monitoring, and health care system for surrounding environment information collection and processing and to initiate action according to the result of processing. According to the type of node, there are two types of sensor network:-homogeneous network and heterogeneous network. In homogeneous network, all nodes are with same characteristics whereas in case of heterogeneous network they can be of different characteristics. Heterogeneous wireless sensor networks better in comparison to homogeneous network as they support high lifetime and high coverage.

The main constraint of WSN is limited energy. WSN meant for object detection and tracking must have sufficient lifetime to complete the desired operation and must have full coverage of the monitoring area. Otherwise, the quality of operation cannot be relied. At the same time, while designing the network for this kind operation the cost factor cannot be ignored. Having powerful nodes in a network to have large network lifetime is not sufficient to have actually the long network life .Also, the power should not be wasted in unnecessary communications and should be properly utilized. One of the way to minimize the unnecessary power usage is to have a proper node deployment scheme for the designated application. There are two important factors relating to any node deployment scheme:-node density and node location. Node density is defined as the minimum number of nodes required to cover a given area. Determining optimum node density is a NP complete problem. Low node density creates coverage hole which creates problem in achieving accuracy in result and may initiate wrong action in response to the result. Similarly, high node density increases number of routes to base station (BS) and number of communication which leads to wastage of energy. High node density also increases the system cost. Therefore, determination of optimum node density is very much important to maintain the quality of the network.

There are two types of node deployment: random deployment and deterministic deployment [1, 2]. In random deployment, sensor nodes are randomly placed in the target area and hence there is the chance of creation of coverage hole in the network. This type of deployment is well suited for large WSN and particularly in the area which is inaccessible easily to the human being. In deterministic deployment, sensor nodes are deployed in pre-calculated position and hence suitable for small size WSN. From the point of network cost factor, deterministic deployment is costly if the size of the network is kept constant for both types of deployments.

There are two types of sensing models: binary disk sensing model and probabilistic sensing model [1, 2].

Three are three different types of coverage of target area:- blanket or full coverage, barrier coverage and point coverage [1, 2]. In full coverage, entire monitoring area is covered by sensors. In barrier coverage, barrier of the sensor nodes are monitored whereas in point coverage method, the point of interest is covered by sensor nodes. Blanket coverage is most suited for object detection and tracking operation. The factors that affect the coverage are characteristic of sensor nodes and coverage algorithm adopted for the application.

This paper considers the problem of node deployment in terms of node density, maximization of coverage area, network lifetime and network cost. Node density has the direct impact on lifetime of the network, network coverage and cost of the network. For a target tracking WSN, the quality of the tracking depends on both network coverage and network lifetime. The cost of the network is directly proportional to the node density. Network coverage depends on node density and location of nodes in the monitoring area.

The rest of the paper is organized as: Section II gives a description of the related works, Section III describes the terminologies defined, problem statement, Section IV gives a description of proposed model and Section V gives the description of performance evaluation of the proposed model.

II. Related Work

Balancing the deployment quality and deployment cost is a challenging task in random deployment in wireless sensor networks. Connectivity in the network depends on the node density and network coverage. Though a lot of research works are done in past to address this issue, still no work is robust. While some papers focuses on maximization of network coverage, some focuses on cost of the deployment. But the WSN designed for object detection and tracking operation must have a balanced feature of maximum network coverage, cost of deployment and energy efficiency. This section gives a description of earlier attempts made by researchers to solve this issue.

B. A. Fuhaidi et al. [3] have proposed a node deployment model based on harmony search algorithm (HSA) and probabilistic sensing model (PSM) in which attempt is made to maximizing network coverage with minimum cost. The cost of the deployment is controlled by controlling the number of mobile nodes to be deployed in the area of interest (AOI). The area of interest is divided into a number of equal sized cells and the centre of the cell is considered as target point. Thus, AOI contain a set of target point. Static nodes are deployed using random deployment scheme initially. PSM is used to calculate the network coverage using target point set. If two or more sensors cover the same target point, then, it is said that sensors are overlapped. The probability of coverage overlapping is determined on the basis of coverage threshold. Next, mobile nodes are added according to the requirement. HSA is used to optimize the mobile node location so that overlapped region can be minimized. The authors claim that the proposed model contains less number of nodes and has maximum network coverage in comparison to homogeneous deployment and HEWSN model. No doubt, heterogeneous wireless sensor networks are better in comparison to homogeneous wireless sensor network and are more useful for the application like object detection and tracking. This feature cannot be ignored in the name of cost because quality of operation also matters. So, there is a need of balancing between different types of nodes used in the network so that quality will not be compromised. The authors have not considered this matter. C. Zygowski and A. Jaekel [4] have proposed an algorithm based on mixed integer linear programming for effective path planning for mobile nodes to fill the coverage hole and to maximize area coverage. The algorithm focuses on minimum distance travel for mobile nodes and in minimum time. The deployment cost is not taken into consideration here. I. Alablani and M. Alenazi [5] proposed a node deployment strategy named Evaluated Delaunay Triangulation-based Deployment for Smart Cities (EDTD-SC) that focuses on sensor distribution and sink placement in smart cities. The algorithm utilizes Delaunay triangulation and k-means clustering to optimize the node location to improve coverage while maintaining connectivity and robustness with obstacles existence in the area of interest. The deployment scheme outperforms random and regular deployment in terms of network coverage. The work is suitable for small sized network and do not explore the feature of heterogeneity in node deployment. P. Prabhaharan et al.[6] have proposed an adaptive virtual force algorithm for node deployment in hybrid wireless sensor network meant for object tracking. Initially, static nodes are deployed and coverage hole is determined. Then, for hole patching mobile nodes are used. The optimum location of the mobile nodes is calculated using adaptive virtual force algorithm. The scheme does not focus on the cost of the network. J. Mao et al.[7] have proposed a partitionable polyhedral node deployment scheme for warehouse monitoring systems. This scheme proposes a node deployment collaborative perception model based on 0-1 perception model and exponential model. The 3D space is divided into a number of voronoi cells and at the center of each cell, one sensor is deployed. The work focuses on maximization of coverage area and uses deterministic deployment. F. Alassery [8] has proposed a node deployment design based on virtual multiple-input multiple-output technology to increase the performance of cluster based wireless sensor network. The height of the antenna of nodes is taken into consideration as an additional parameter for node deployment. This is helpful in increasing transmission range of nodes and minimizing relay nodes. X. Song et al. [9] have proposed a secure node deployment scheme based on evidence theory approach and caters for 3D underwater wireless sensor networks. This scheme implements sonar probability perception and an enhanced data fusion model to improve network coverage. It requires fewer nodes for large coverage area without compromising the quality of detection ability. Also it focuses on lifetime of the network. The cost of deployment is not considered here. S.M. Koreim and M.A. Bayoumi [10] have proposed a coverage hole detection algorithm for detecting coverage hole in wireless sensor network resulted due to damage of sensor nodes in area of interest due to flood or fire spreading. The algorithm partitions the area of interest into equal sized cells and each cell is cut into different triangles and then identifies the triangles that are not covered by any sensor. The triangles are formed with the help of three neighbouring sensor nodes. Energy efficiency here is achieved by minimizing the number of participating sensor nodes for hole detection. S. S. Kashi [11] proposed an algorithm named Heterogeneous Distributed Precise Coverage Rate (HDPCR) that detects holes and calculates coverage area of heterogeneous wireless sensor network using localized mechanism. Boundary detection mechanism is used to determine the boundary of the hole area. A. Katti and D. K. Lobiyal [12] have proposed deterministic 3D node deployment strategy for wireless sensor network that includes prism deployment, pyramid deployment, cube deployment, hexagonal prism deployment for finding coverage prediction. It also determines the minimum number of sensor nodes required for specific coverage prediction. They have also proposed a scheduling algorithm for enhancing network lifetime. The work is suitable for small sized network. K. Wei [13] proposed a novel node deployment algorithm based on multi-objective evolutionary algorithm that optimizes average energy consumption, average sensitivity area and network reliability. In order to achieve the objectives, they have improved MOEA/D method by incorporating uniform design to generate aggregation coefficient vector and quadratic approximation for local search. The algorithm is designed for homogeneous network and no attempt is made to balance the energy efficiency and quality of operation.

N. Rai and R. D. Daruwala [14] have proposed an empirical formulation for estimation of randomly deployed nodes for attaining desired coverage for any size network. The formula includes the parameters that affect the optimum number of nodes. The formula is based on regression analysis using least square polynomial curve fitting technique. Sensor device characteristics are taken into consideration to devise the formula. Mainly, the authors have focussed on node density for desired coverage. S. Indumathi and D. Venkatesan [15] have proposed a dynamic node deployment model using genetic algorithm with gap cluster technique that uses different types of sensors. Gap cluster technique is used to determine the coverage hole resulted after initial deployment of nodes. In order to improve the network coverage and to minimize the number of gap clusters, additional nodes are deployed in gap region. The authors have not focused on the issue of energy efficiency and cost of the deployment. J. W. Lee and W. Kim [16] have proposed randomly deployed node deployment scheme that uses swarm intelligence for improving network lifetime and network coverage for heterogeneous wireless sensor network. This paper uses binary valued swarm intelligence algorithm such as Particle Swarm Optimization, Ant Colony Optimization, and Artificial Bee Colony Optimization. The work considers two types of nodes such as ordinary nodes and powerful nodes and focuses on minimization of network cost by minimizing number of nodes without compromising guaranteed coverage. The work is silent about how to handle the coverage hole problem in the network. M. R. Serik and M. Kaddour [17] have proposed a node deployment scheme for camera based wireless sensor network which focuses on optimization of deployment cost by minimizing the number of camera nodes required to cover a set of target objects with a pre-defined level of quality, position of camera nodes and orientation of camera nodes. Binary particle swarm optimization algorithm is used to minimize the number of camera nodes. The work is silent about energy efficiency of the network. Y. Yoon and Y. H. Kim [18] have proposed a node deployment algorithm based on the genetic algorithm for maximization of network coverage. A mixture of different types of static sensors is used for the deployment. The work focuses on the determination of number of sensor of each type while maximizing network coverage. Network coverage is determined using Monte-Carlo method. When the sample size is very large or very small this way of network coverage calculation gives incorrect result. Z. Kang et al. [19] have proposed a decentralized, coordinate free, node based coverage hole detection algorithm which uses boundary critical points to determine hole and uses concept of perpendicular bisector for hole patching. The algorithm is suitable for grid type network and randomly deployed network. The objective of the algorithm is to achieve full coverage. S. Babaie and S. S. Pirahesh [20] have proposed a method that detects holes and their sizes in area of interest using voronoi diagram. Then holes are filled with mobile sensors. The issue of deployment cost and energy efficiency are not addressed. J. Wang et al. [21], proposed a PSO based energy efficient coverage control technique for homogeneous wireless sensor network in which the network in which the node locations are adjusted with respect to the coverage rate and energy consumption of each grid.

III. Assumptions, Definition and Problem Statement

A. Modelling Assumptions

- The area of interest is a two-dimensional plane area over which sensor nodes are randomly deployed.
- Sensor network is a heterogeneous sensor network.
- Sink knows the location of all nodes.
- Sensing region of a sensor is a circle.
- Cost of deployment is only based on number of nodes used for the deployment.
- Energy consumption is minimized by minimizing number of communication with the sink at the time of deployment.
- As network lifetime depends on energy consumption, by minimizing energy consumption lifetime can be increased.
- There is no obstacle in the network and the environment is noise free.
- Target object can be detected if it is in the sensing range.

B. Definitions

Let ST= {1, 2,….., n} are the static nodes and MB={1,2,…..,m} are the mobile nodes are to be deployed on the area of interest. Out of m mobile nodes, some nodes are powerful mobile nodes and some nodes are ordinary mobile nodes. Area is divided into m1×n1 grids and each cell size is d × d where d is the diameter of sensing disk of static sensor (see Fig. 1). Let S= $\{s_1, s_2,\ldots s_k\}$ is the set of k subsets, where k is the number of cells present in the area of interest(AOI). Each subset k_i consists of end points and center point of a cell: $s_i = \{(x_{i1},y_{i1}),(x_{i2},y_{i2}),(x_{i3},y_{i3}),(x_{i4},y_{i4}),(c_{ix}, c_{iy})\}$, where,$(x_{ij}, y_{ij})$, j=1….4 are the end points of the cell and (c_{ix}, c_{iy}) is the center point of cell. A cell is individually analyzed to determine the hole.

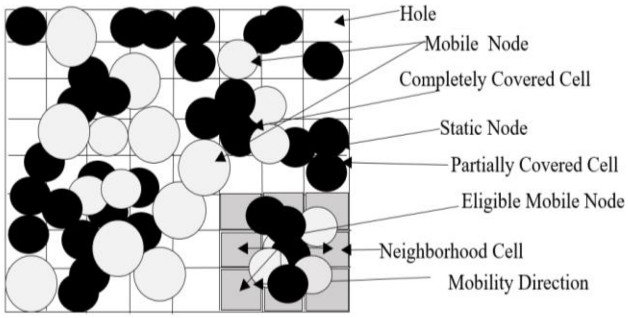


Fig. 1. Graphical Representation of Definition of Different Terminologies.

- Completely Covered Cell:-A cell i is said to be completely covered if all the points belonging to subset si is covered by sensors.
- Partially Covered Cell: - A cell i is said to be partially covered if at least one points belonging to subset si is not covered by any sensors and there is no intersection between the cell i and any of the sensor's sensing range.
- Uncovered Cell: - A cell i is said to be uncovered if none of the points belonging to subset si is covered by any sensors and there is no intersection between cell and sensing disk which is assumed as circle here.
- Hole:-It is the uncovered portion of cells.
- Hole Segment:-It is the area covered by adjacent holes.
- Eligible Mobile Nodes:-The mobile nodes whose sensing region is completely or partially overlapped with the sensing region of static nodes are said to be eligible mobile nodes.
- Neighborhood Cell:-Each cell is surrounded by eight equal sized neighborhood cell. A neighborhood cell of a cell may be uncovered, covered, partially covered by sensors.
- Optimum Location of Mobile Node:-It is the location that maximizes network coverage with minimum power usage if a mobile node is relocated to this location.
- Mobility Direction for Mobile Nodes:-An eligible mobile node can travel in any direction to cover the hole.
- Coverage Ratio:-It is the ratio between total covered cell and total number of cells present and its value lies in the range of [0, 1].
- Detection Accuracy: - It is the ratio between the area under sensing coverage and the size of the AOI.

C. Problem Statement

In a WSN designed for object detection and tracking, the full coverage of area of interest is required for continuous tracking of object. But when the nodes are deployed randomly across the region, coverage holes are created which leads to frequent failing of detecting the target even if the target is present. The matter worsens when the hole is present at the boundary of the area of interest and the size of the hole is large. One of the solutions to it is to deploy additional nodes. Though, deployment of additional nodes helps to achieve full coverage but this limits network lifetime and increases network cost. Thus, there is a need of economic deployment plan that balances network coverage and network lifetime.

IV. PROPOSED MODEL

A. Optimum Number of Node Determination

This step deals with calculation of optimum number of nodes required to achieve desired coverage. Nodes deployed in the area of interest are a mixture of static and mobile nodes. *M* number of powerful mobile nodes and N number of ordinary nodes are used. One-third of *N* ordinary nodes are mobile nodes and remaining two-third nodes are static nodes. Ordinary nodes are with same sensing range, transmission range and battery power. Powerful mobile nodes are with high sensing range, transmission range and battery power in comparison to static nodes. The optimum number of powerful mobile nodes and ordinary nodes are determined using Particle Swarm Optimization (PSO) Based Technique [21, 22]. The PSO is a meta-heuristic optimization algorithm which is based on the behavior of the birds. The steps of the algorithm are given in Fig. 2.

1. Initialize Population and define search parameters
2. Initialize the velocity and position of the swarm. Also initialize best value of individual swarm ($Pbest_i$) and global best (*Gbest*)
3. Find the fitness of the swarm using objective function
4. Update $Pbest_i$ and *Gbest*
5. Update the position and velocity of the swarm

The equation for updation of position and velocity are:

$v_i(t + 1) = w*v_i(t) + c_1r_1[Pbest_i (t) - x_i(t)] + c_2r_2[Gbest(t)- x_i(t)]$

$x_i(t+1)=x_i(t)+v_i(t+1)$

where, *v* is the particle velocity, *x* is the particle position,*r1*& *r2* are random numbers in the range of 0 and 1,*c1*&*c2* are learning factors. *w* is the inertia weight.

6. Repeat steps 3 to 5 until termination criteria is reached.

Fig. 2. Pseudo-Code of PSO Algorithm.

The objective function for node optimization is:

$$Minimize\ f(N,M) = N + M \quad subject\ to$$
$$C_{coverage}(N,M) \geq C_{guaranteed\_coverage}$$
$$and\ N > 0\ and\ M > 0 \tag{1}$$

Where, $C_{coverage}(N,M)$ is the total area covered by *N* and *M* number of sensors. $C_{guaranteed\_coverage}$ is the desired coverage area.

$$C_{guaranteed\_coverage} = \sum_{i=1}^{N} S_R + \sum_{i=1}^{M} S_{R1} \tag{2}$$

Where, S_R and S_{R1} are sensing range of ordinary sensor and powerful sensor respectively.

$$C_{coverage} = (1 - e^{\pi\lambda})(1 - e^{-\pi\lambda}) \tag{3}$$

Where, $$\lambda = (N \times S_R^2)/||A|| \tag{4}$$

Where ||A|| is the area of the monitoring area.

$$\lambda' = (M \times S_{R_1}^2)/||A|| \quad (5)$$

λ and λ' represents the probability of a point being covered by normal node and heterogeneous node respectfully.

$\left(1 - e^{\pi\lambda}\right)$ is the mean of the probability of covering a point by N normal nodes in the given area and $\left(1 - e^{\pi\lambda'}\right)$ is the mean of the probability of covering a point by M heterogeneous nodes in the given area.

$$F(N,M) = \begin{cases} f(N,M), if\ g(N,M) \geq 0, N > 0, M > 0 \\ fmax + |g(N,M)|, otherwise \end{cases} \quad (6)$$

Where $f_{\max}$ is the worst fitness value of particles. *g(N,M)* is a normalized constraint which is calculated as follows

$$g(N,M) = \left(\frac{C_{coverage}(N,M)}{C_{guaranteedcoverage}}\right) - 1 \quad (7)$$

B. Hole Determination

This step deals with the identification of hole in cells and calculating the size of the hole. The process of hole determination in a cell is treated here as the case of intersection of circle and rectangle. Each circle is a sensing disk and each rectangle is a cell in the area of interest. Let *A*, *B*, *C*, *D* are the end points of the rectangle. *E* and *R* are center and radius of the circle, respectively. A circle intersects a rectangle if the distance between the point of the rectangle closest to the center of radius is less than the radius of the circle. If (p_x, p_y) is an end point of the rectangle and (q_x, q_y) is the center of the circle and then, the Euclidean distance between them is:

$$distance = sqrt((p_x - q_x)^2 + \left(p_y - q_x\right)^2) \quad (8)$$

The hole area in the cell is determined using the formula of circle, sector, triangle and intersection of lines. If no end points are inside the circle and there is no intersection between circle and rectangle, then there is no overlapping between circle and rectangle and the rectangle is completely a hole. If all the end points are inside the circle, then circle has completely overlapped the rectangle. Different cases of intersection between and circle are:

1) All the end points of the rectangle are inside the circle.
2) Circle completely inside the rectangle.
3) Circle intersecting one side of rectangle.
4) Circle intersecting two adjacent sides of rectangle (including and excluding corner).
5) Circle intersecting two opposite side of the rectangle.
6) Circle intersecting three sides of the rectangle.
7) Circle intersecting four sides of the rectangle.

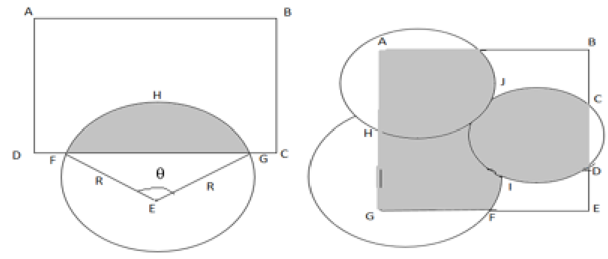
Following is an example of calculation of hole in a rectangle when circle intersects one side of rectangle. See Fig. 3(a). Let L and length and B is breadth of rectangle, θ is the angle of sector and R radius of the circle, and radius of both circles are same then,

Hole in ABCD rectangle = (L×B) –Area of shaded region (9)

For Fig. 2(a),

Area of shaded region= $0.5 \times R^2 (\theta - \sin\theta)$ (10)

Where, θ is the angle between two sides of the sector.



(a) (b)

Fig. 3. (a)-(b): Intersection of Circle and Rectangle.

For the case of Fig. 3(b), individual case of overlapping is determined and then circle-circle intersection area is determined to calculate the hole region in the rectangle. The area of overlapped portion is the difference between area of rectangle and (sum of the shaded portion of circle-overlapped area of circle).The area of overlapping *AO* between two circles for circles having two different radius *r* and *R* is calculated as follows:

$$AO = r^2 \times \text{atan2}(t, d^2 + r^2 - R^2) + R^2 \times \text{atan}(t, d^2 - r^2 + R^2) - (\frac{t}{2}) \quad (11)$$

Where, *d* is the distance between center of two circles and

$$t = \sqrt{(d + r + R)(d + r - R)(d - r + R)(-d + r + R)} \quad (12)$$

If *t* does not contain any imaginary part, there is no intersection between circles.

There may be single hole region or multiple hole region in a rectangle. The area of hole in a rectangle is determined as:

$$Hole_{Area_i} = \sum_{j=1}^{k} A_j \quad (13)$$

Where *k* is the no of hole regions present in the i_{th} rectangle. A hole segment consists of adjacent hole regions (see Fig. 4).

$$Hole_{AOI} = \sum_{j=1}^{m1 \times n1} A_j \quad (14)$$

Where $Hole_{AOI}$ is the total hole area in area of interest and *m1*×*n1* are the number of cells in area of interest.

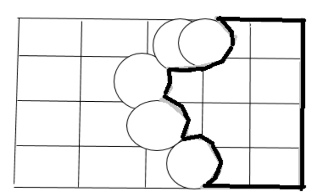


Fig. 4. Hole Segment (Black Marked Region).

C. Hole Filling

Ordinary mobile node movement is restricted to the hole region of neighborhood cell whereas powerful mobile nodes can travel optimum distance to cover the hole area. By doing so, energy consumption can be minimized at the time of node redeployment and network coverage can be maximized. First, the list of eligible nodes for relocation is prepared. In the first phase, eligible ordinary mobile node movement is done and they are moved to the optimum location of the neighborhood. The node must move at most *d1* distance towards neighboring hole region to maximize coverage. See the Fig. 5(a), *A* and *B* are the center of two circles respectively. *C* and *D* are the intersection point of two circles. *AG* and *BF* are the radius of first and second circle respectively. The value of *d1* is calculated as follows:-

$$d1 = FG + rand \quad (15)$$

Where $FG = FE + EG$ and $rand$ is a random number in the range of [0, 1]. FE and EG can be calculated using the equation for calculating the area of the circular segment in a sector of a circle. New location in the neighborhood is shown in Fig. 5(b). Hole area in each concerned cell is updated after relocation of ordinary mobile nodes.

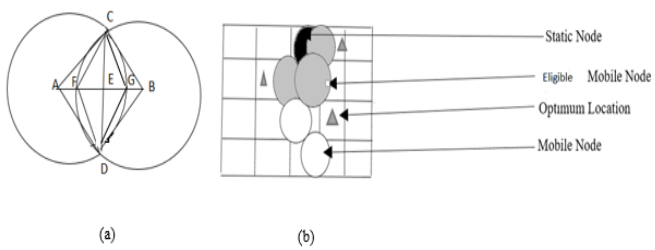


Fig. 5. (a) Width of Overlapping Sensing Area between Two Nodes (b) Optimum Location for Relocation of Ordinary Mobile Node.

In second phase, the optimum location of the eligible powerful nodes is decided for relocation in order to increase the network coverage. PSO algorithm is used to determine the optimum location of these mobile nodes. The objective function here used is

$$f(x_{new}, y_{new}) = ((x_{old} + U_{u1}), (y_{old} + U_{u2})) \quad (16)$$

Subject to $((\sum_{i=1}^{N} \pi r^2 + \sum_{j=1}^{M} \pi R^2) - A_{ov}) > TC$

$0 > U_{u1} \leq X$ and $0 > U_{u2} \leq Y$

Where (x_{new}, y_{new}) is the new location of eligible powerful mobile node, (x_{old}, y_{old}) is the current location of it. U_{u1} and U_{u2} are the amount of change required in x-direction and y-direction, respectively. *TC* is the area coverage currently and A_{ov} is the overlapping area. *X* and *Y* define AOI size.

$$U_{u1} = \min(diff_{x1}, diff_{x2}, diff_{x3} \ldots\ldots, diff_{xk}) \quad (17)$$

$$U_{u2} = \min(diff_{y1}, diff_{y2}, diff_{y3} \ldots\ldots, diff_{yk}) \quad (18)$$

Where $diff_{xi}$ is the distance between x-coordinate of node and the x-coordinate of centroid of hole *I*, $diff_{yi}$ is the distance between y-coordinate of node and the y-coordinate of centroid of hole *i*.

The flowchart of the proposed model is given Fig. 6 and its corresponding algorithm is described below:

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1. *Initialize the AOI size*
2. *Determine number of static nodes, ordinary mobile nodes and powerful mobile nodes required for desired coverage in AOI.*
3. *Initialize sensing radius of all sensors*
4. *Deploy all nodes randomly*
5. *Divide AOI into grids and define coordinate of each cell.*
6. *For i=1 to number of cells //Hole Detection and its size //calculation*

   NS=0;

   Cell$_i$= End points of cell i

   For k=1 to size(Cell$_i$)

   For j= 1 to number of sensors

   Calculate d(j) for all end points of ith cell

   If d(j)<sensing range

   Update NS by 1.

   End

   End

   End

   For j= 1 to number of sensors

   Find the intersection between ith cell and jth sensor

   End

   If NS==0 and there is no intersection between sensor and cell

   Cell_status(i)='Hole'

   Store the Hole area size

   Else if NS==4

   Cell_status(i)='Completely Covered'

   Else if NS<4 and there is overlapping between sensor and cell

   Cell_status(i)='Partially Covered'

   End

   If Cell_status(i)=='Partially Covered'

   Identify hole regions and calculate their size

   Find the sum of all hole regions

   End

   End
7. *Calculate the total Hole size in AOI*
8. *For j=1 to number of mobile nodes //Hole Filling*

   Determine the eligible mobile nodes for relocation

   End
9. *For i=1 to number of eligible ordinary mobile nodes*

   Determine the new location for nodes in neighborhood

   End
10. *For i=1 to number of eligible powerful mobile nodes*

    Determine the new location for nodes in AOI

    End
11. *Calculate Hole size in AOI*

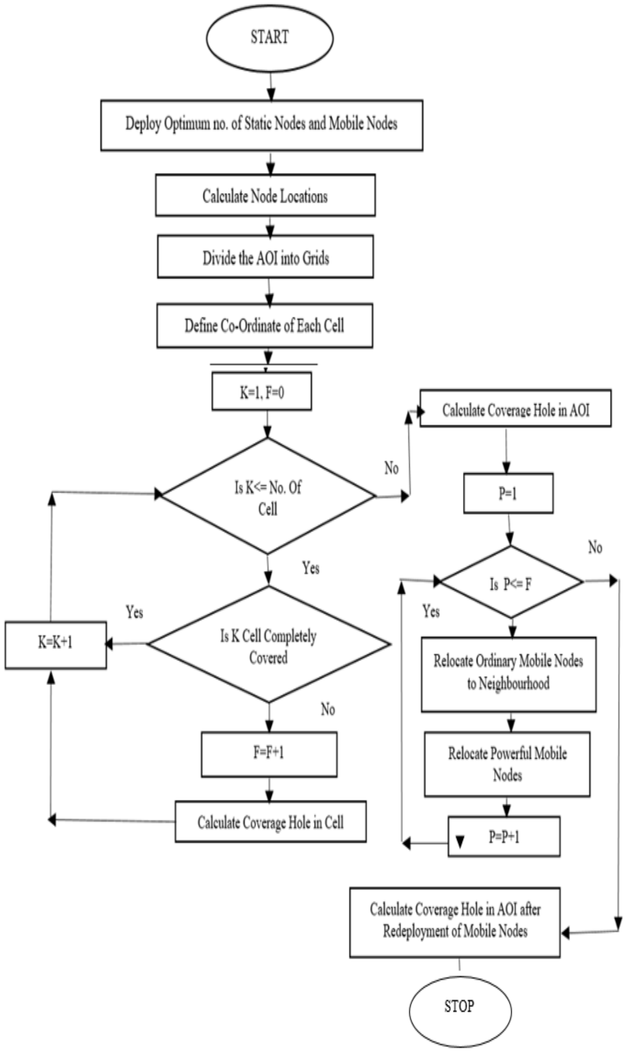


Fig. 6. Flow Chart of Proposed Model.

D. Energy Model

For static node, energy consumption is negligible at the time of deployment and hence, the consumption value is neglected. In case of mobile nodes, it is based on the distance travelled by the node and the communication done with sink. If each packet size sent to the sink is *k*-bit and each node sends one packet to sink and receives one packet from the sink, then the power consumption for sending and receiving packet from sink, the following set of equation can be used to calculate the energy consumption by the mobile node.

$$E_{TX}(k,d) = \begin{cases} k * E_{elec} + k * E_{amp} * d^2, if\ d < d_0 \\ K * E_{elec} + K * E_{fs} * d^4, if\ d \geq d_0 \end{cases} \quad (19)$$

Where $E_{TX}$the energy required for packet transmission, d is the distance between source and destination and d_0 is the threshold distance. E_{elec} is the base energy which required to run the transmitter or receiver. E_{fs} and E_{amp} are the unit energy required for transmitter and amplifier.

Where, $d_0=\sqrt{\frac{E_{fs}}{E_{amp}}}$ (20)

The energy required for receiving k-bit message is:

E_{RX}(k)= k* E_{elec} (21)

Let E_{RELOC} is the energy required to relocate a node from one location to other location situated at distance *d*. E_{RELOC} depends on the distance between old location and new location of the same node. Then the total energy consumed by the node for movement from one location to other is:

$$E_c = E_{TX}(k,d) + E_{RX}(k) + E_{RELOC} \quad (22)$$

V. Performance Evaluation

A. Simulation Environment and Parameter Setup

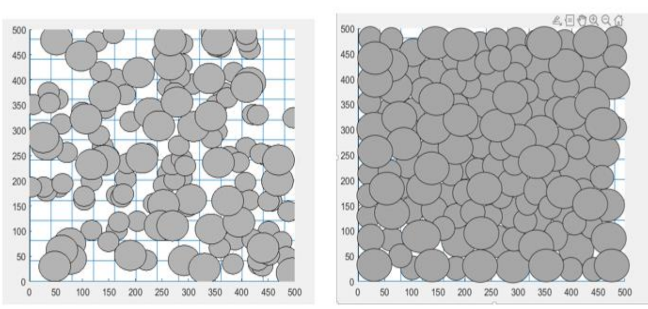
The proposed model is simulated using MatLab R2020b. The AOI size is 500m×500 m. The network is a heterogeneous wireless sensor network and nodes are deployed randomly. All static and ordinary mobile nodes are with same sensing radius and same battery power. The only difference is the mobility. The sensing radius and battery power for this category homogeneous node are 20m and 5J respectively. To reduce the power consumption in case of ordinary mobile nodes during node deployment, their mobility is restricted to short distance. Powerful mobile nodes are with sensing radius of 30 m and battery power of 10J.The communication range in case of all nodes are the twice of their sensing radius. The location of the sink is [500,500]. The total number of nodes required for full coverage of AOI is calculated using PSO algorithm i.e. the number of same characteristic nodes N and powerful nodes M are optimized. One-third of N nodes have the mobility. The coverage degree k=1. Total 60 static nodes, 30 ordinary mobile nodes and 46 powerful mobile nodes are used for deployment. For the movement of ordinary mobile nodes, a 3×3 mask is used and 8-neighborhood cells of the cell containing overlapped mobile node is determined. The ordinary mobile node is moved to the hole present in the neighborhood. For the powerful nodes, PSO algorithm is used to determine the optimum location. Algorithm runs for 200 iterations. As one of the factor that affects the network cost is the number of nodes used for deployment, we assume that the cost can be minimized if the number of hardware to be used is minimized. Also, when the number of nodes is minimized, number of communication between sink and nodes are minimized. Hence, Energy is saved. Following are the values of PSO parameter: c1=c2=2, 0.4≥w≤0.9, v=0.1×InitialPosition, number of swarm=100.The values of parameters for harmony search algorithm are: hms=5, hmcr=0.95, par=0.25, bw=0.2, numRows=30.

B. Simulation Result

Fig. 7(a) shows the random deployment of nodes in AOI resulting multiple coverage hole and Fig. 7(b) scenario after hole filling. The quality of operation in a network mainly depends on network coverage and lifetime of the network. There is a direct relationship between lifetime of the network and network coverage. Also, when an object is in the hole region is not detected by any sensor. Object's movement is simulated and the moving path is a simple straight line. At every 't' time interval, a sensor searches for presence of an object in its sensing coverage area.. So, the detection accuracy depends on the maximum area coverage. Hence, we define the object detection accuracy in terms of sensing area coverage. Fig. 7(b) shows the status of AOI after moving mobile nodes to the hole region. Fig. 8(a) and 8(b) conveys that the network coverage increases when the overlapping area between sensors are decreased. Fig. 8(c) shows the energy consumption during movement of mobile node. Table I shows the performance of the proposed algorithm for varying area size with constant sensing range of nodes.

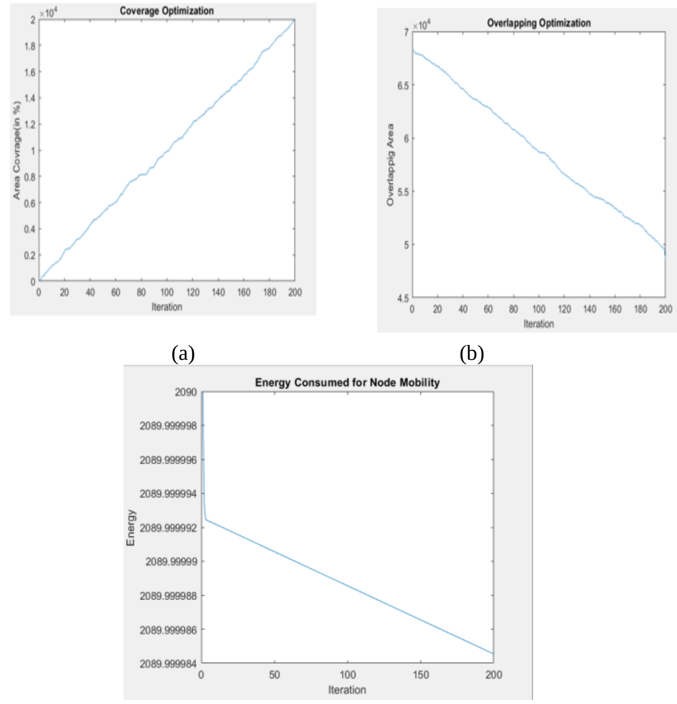
In Table II, area size(AS) is 500×500 m². SR_1 is the sensing range of static sensor and ordinary mobile sensor. NS is the number of static node, NOM is the number of ordinary mobile node and NOP is the number of powerful mobile nodes. CBD is the coverage before deployment and CAD is the coverage after deployment. SR_2 is the sensing range of powerful mobile sensor. Coverage ratio(CR) is the ratio of number of cell fully covered by total number of cells. From the Tables I and II, it is clear that coverage ratio depends on the on the location of sensor nodes in AOI. Fig. 9(a) and 9(b) shows the performance comparison between the proposed model and other existing model. The number of nodes shown in the Fig. 9 is for different area sizes mentioned in Table I. From Fig. 9(a) and 9(b), it is clear that coverage ratio and energy efficiency of proposed model is better in comparison to HSA and PSO algorithm. Both HSA and PSO based node deployment technique are silent about the effect of node density on energy efficiency and cost of the deployment.

Using static nodes only for deployment makes the system cheaper but creates a lot of coverage hole in AOI which greatly affects the quality of operation, particularly when the network is used for object tracking application. Coverage holes resulted the missing of object and hence increases the rate of reporting the false negative message about object's presence. It is obvious that when coverage hole minimizes, object detection rate increases under the assumption that the environment is noise free and the signal attenuation is in the tolerable limit. The detection accuracy is directly proportional to the coverage area. Proposed model achieves 97% accuracy in the case of no obstacle in the monitoring area and the surface area is a 2d-plane.



(a) (b)

Fig. 7. (a) Node Deployment before Node Location Optimization (b) Node Deployment after Node Location Optimization.



(a) (b)

(c)

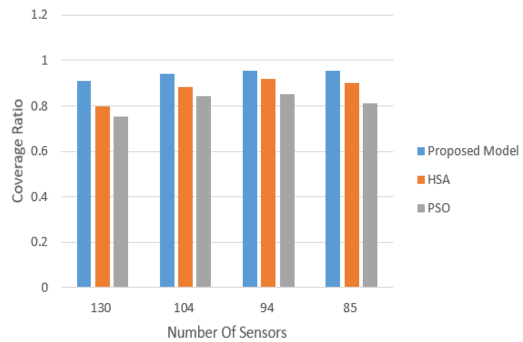
Fig. 8. (a) Sensing Area Coverage Optimization (b) Overlapping Area Optimization (c) Energy Consumed for Node Movement of Proposed Model.

TABLE I. PERFORMANCE OF PROPOSED MODEL FOR DIFFERENT AREA SIZE FOR CONSTANT SENSING RANGE

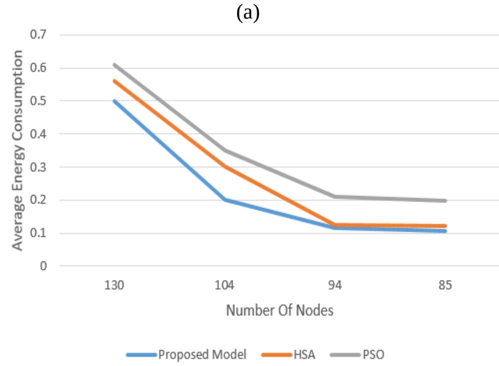
AS (in m²)	NS	NOM	NOP	CBD (in %)	CAD (in %)	CR
500 × 500	60	30	40	76.6760	96.9956	0.9100
400 × 400	59	30	15	61.7031	91.9300	0.9400
300 × 300	59	30	15	80.9911	93.3933	0.9531
350 × 350	53	27	14	78.5889	93.3933	0.9531
200 × 200	47	24	14	80.2300	91.5622	09531

TABLE II. PERFORMANCE OF PROPOSED MODEL FOR SAME AREA SIZE WITH DIFFERENT SENSING RANGE

SR_1 (in m)	SR_2 (in m)	NS	NOM	NOP	CBD (in %)	CAD (in %)	CR
20	30	60	30	40	74.6760	96.9956	0.9100
15	30	68	34	54	51.1996	94.1908	0.8713
25	30	56	29	25	40.6496	92.2032	0.8260
20	25	63	31	55	57.2932	94.9696	0.8505
15	20	115	57	82	75.8592	96.4364	0.9273



(a)



(b)

Fig. 9. Performance Comparison of Proposed Model with Other Model (a) Coverage Ratio (b) Average Energy Consumption.

Using mobile nodes only for deployment achieves high quality of operation by achieving full coverage but makes the system costlier. So, the proposed model tries to balance between cost of the system with quality of operation by considering both type of nodes for deployment. To calculate the deployment cost, we have considered the hardware cost only. Let for deploying a static node, deployment cost is 1 unit of money, for ordinary mobile node it is 1.5 unit of money and 2 unit of money for powerful mobile node, then, the deployment cost for an area of size 500×500 m^2 is 185 unit of money.

VI. Conclusion

Network coverage and connectivity is the one of the factor on which the object detection accuracy in WSN depends. Coverage hole problem is a common problem in a randomly deployed network. Presence of object in hole region cannot be detected and necessary action cannot be initiated. The full coverage of AOI is desired which can only be achieved by deploying additional mobile nodes in hole region. It is exactly difficult to calculate that how many mobile nodes will be deployed. A large number of mobile nodes increases the deployment cost and shortens network lifetime whereas the small number of mobile nodes will not be able to fill the hole. In our work, we have tried to balance the number of mobile nodes with network cost and energy. We assume that when the number of nodes is minimized, number of communication can be minimized which in turn will increase energy efficiency. Proposed model uses a mixture of static nodes and two types of mobile nodes. Number of static nodes and mobile nodes for deployment are optimized using PSO algorithm. After initial deployment, the overlapped ordinary mobile nodes are shifted to the hole region present in the neighborhood. For determination of destination for them, a 3×3 mask is used and 8-neighborhood cells are determined. Nearest destination is the new location of the ordinary mobile node. For powerful mobile nodes, the new location is determined using PSO algorithm. The performance of the proposed model is evaluated and its coverage ratio is 0.91 and coverage percentage is 96.9956. Its performance is compared with other existing algorithms and the proposed model is found better in comparison to other. The detection accuracy for the proposed model is 97%. In future, we will try to focus on other artificial intelligence techniques that can further improve the detection accuracy by improving the coverage ratio. In this work, we have considered the disk model of sensing for coverage calculation. We will also focus in other model of sensing for the same.

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