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Hybrid Node Deployment Algorithm to Mitigate the Coverage Whole Problem in Wireless Sensor Network

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Abstract: Due to random deployment of static sensor nodes and environmental factors existence of holes in wireless sensor networks is inevitable. This holes results in reducing the data transmission performance and in additional energy consumption. Consequently, the hole problem is an important factor for prolonging the network lifetime. The network lifetime can be improved by deploying additional mobile sensors with the initial static sensor deployment. Finding the number of additional sensors used is a optimization problem. To solve this we are proposing a Hybrid Electromagnetism like algorithm (EM) with genetic operators to obtain the best/optimal coverage of network area by sensor nodes. A new approach calculates the coverage rate of the sensors by using binary detection model and applies the EM with genetic operators in order to obtain the optimal solution within the minimum iterations. A simulation result shows that the Hybrid EM algorithm with genetic operator performs better than basic GA based node redeployment.

Key words: Coverage hole · Node deployment · Coverage hole healing · Mobile sensors · Hybrid sensor network · Lifetime

INTRODUCTION

In recent years, the rapid developments of wireless communication technology and microelectronics enables wide application of the low-cost, low-power, multi-function and tiny wireless sensor nodes. Hundreds and thousands of wireless sensor nodes distributed throughout a particular area constitute a wireless sensor network (WSN).[1] WSNs have widespread application value and prospect in both military and civil fields, such as environmental monitoring, inventory management, disaster recovery, object tracking and intrusion detection and so on [2]. The Deployment of WSN may vary from application to application. It may contain static sensor or mobile sensor or hybrid of both the sensors.

One of the key points in the design stage of a WSN that is related to the sensing attribute is the coverage of the sensing field. In the literature, the coverage problem in WSNs has been addressed either as point coverage or area coverage [3]. While area coverage protocols are designed to maximize the area of the sensing field that could be covered, target coverage, on the other hand, assumes that the sensing field is divided into grids. Intersection of these points is called coverage point. Therefore, the main objective of the point coverage protocols is to maximize the number of grid points that could be covered in the field. The coverage issue in WSNs depends on many factors, such as the network topology, sensor sensing model and the most important one is the deployment strategy that is used to distribute or throw the sensor nodes in the field [4]. The sensor nodes can be deployed either manually based on a predefined design of the sensor locations, or randomly by dropping them from an aircraft. Random deployment is usually preferred in large scale WSNs not only because it is easy and less expensive but also because it might be the only choice in remote and hostile environments. However, random deployment of the sensor nodes can cause holes formulation; therefore, in most cases, random deployment is not guaranteed to be efficient for achieving the required objective in terms of the coverage [3].

In order to overcome the problem of holes formulation after initial deployment of the sensor nodes in the sensing field, an efficient algorithm that would maximize the covered area or coverage point should be employed. In WSNs where all nodes are stationary, the

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area of the sensing field and the number of sensor nodes are small, coverage can be maximized by manually deploying additional nodes to the initially deployed ones. However, in large scale WSNs where human intervention is not possible or when the sensing filed is hostile, random deployment is the only choice.

In random deployment, the holes formulation problem might be reduced or eliminated after initial deployment using one of two approaches. In the first approach, if all sensor nodes are mobile, then an efficient algorithm should be designed such that the coverage is maximized while at the same time the moving cost of the mobile nodes is minimized. In this case, the mobility feature of the nodes can be utilized in order to maximize the coverage. After the initial configuration of the mobile nodes in the sensing field, an efficient algorithm such as potential field algorithm or virtual force algorithm can be employed for the purpose of relocating the sensor nodes [5].

In the second approach, if the sensor nodes are hybrid in which some of the nodes are stationary and the other are mobile, an efficient algorithm should be employed in order to find the number and locations of the mobile nodes that should be added after the initial deployment of the stationary nodes. One of the algorithms that can be employed is an optimization algorithm which is used to find an optimal or near optimal solution. This paper proposed an optimization algorithm which is the hybrid of electromagnetism and GA operations to find number of sensor nodes that can be added after the initial node deployment in order to maximize the coverage.

This paper is organized as follows. Section 2 discusses the operation of the GA. Section 3 presents the related work. Section 4 discusses the assumptions and the components of the proposed approach. Section 5 presents simulation experiments and discusses the results and Section 6 concludes the paper

Related Works: The WSN can have static node or mobile node or hybrid of static and mobile sensor networks. This section presents the existing algorithm for each of the category. In [6], the authors proposed 3MeSH (triangular mesh self-healing hole detection algorithm), which is a distributed coordinate-free hole detection algorithm for static sensors. If node detects presence of 3MeSH ring defined by all its neighbors, then it is a boundary node. For detecting large holes, nodes are allowed to collect connectivity information from nodes further away but at the cost of increased complexity.

In [7, 8], authors have used Voronoi diagrams to detect coverage holes in mobile sensor networks. In [9], authors proposed a coverage hole detection method (CHDM) for mobile sensors by mathematical analysis. It is assumed that network consists of mobile nodes each with sensing radius r and communication radius 2r. A node p is defined as neighbor of node q if it lies in its communication range. On the basis of central angle between neighbor sensors, the authors presented different cases to find coverage holes in communication circle around a redundant movable node. To patch hole, a redundant node is moved to an appropriate position inside the hole. In [10], the authors used the basic EM algorithm for dynamic deployment of mobile sensor network and avoid the coverage holes.

Researchers also used the hybrid of static and dynamic sensor nodes in order to improve the coverage. In [11], a bidding protocol was proposed, in which the static nodes are utilized as bidders and a number of mobile nodes move accordingly to satisfy the coverage requirements. In [12], a distributed protocol was proposed that considers the different sensing capabilities of the nodes using realistic sensing coverage model. In this protocol, the static nodes determine the uncovered areas using a probabilistic coverage algorithm and the mobile nodes move accordingly using virtual force algorithm. In [13], several approaches were proposed based on virtual force algorithm and paticle swarm optimization. The obtained solutions were analyzed for better deployment in the region of interest. Recently, a biogeography-based optimization algorithm was proposed in [14] to maximize the coverage area of the network. Genetic algorithms have also been used to solve the problem of optimal node deployment. In random deployment, genetic algorithms are applied to determine near optimal positions for additional mobile nodes in order to maximize the coverage.

In [15], a force-based genetic algorithm was proposed, in which the mobile nodes utilize the sum of the forces used by the neighbors to choose their direction. In [16], a multi-objective genetic algorithm running on a base station was used. The base station determines where the mobile nodes can move to maximize the coverage and minimize the travelled distance. The authors of [17] presented a triangular oriented diagram to detect a hole. The authors connected the center of three adjacent sensors to produce triangle and further presented various possibilities of occurrence of holes and then calculated the area which is not covered by any of them. This uncovered area is coverage hole. The approach is simple as compared to Voronoi diagram construction.

Moreover, it can determine exact area of hole. In [18], the authors proposed a genetic algorithm based node deployment in order to optimize the network coverage and connectivity. They model the location of potential mobile sensor as chromosome in the solution apace of GA.

EM based theory efficiently finds which mobile node should be moved in order get the maximum coverage. But it requires more number of iteration to find the optimal solution. GA based approaches find the optimum position of mobile sensor with the minimum iterations. So in our proposed approach we combine the advantages of both EM and GA to find the best optimal solutions. The purpose of this hybrid framework is to take the advantage of EM, which yields a high diversity population and GA operator let the algorithm converge faster.

Electromagnetism-Like Algorithm: EM simulates the attraction-repulsion mechanism of electromagnetism theory which is based on Coulomb's law [19]. Each particle represents a solution and the charge of each particle relates to its solution quality. The better solution quality of the particle, the higher charge the particle has. Moreover, the electrostatic force between two point charges is directly proportional to the magnitudes of each charge and inversely proportional to the square of the distance between the charges. The fixed charge of particle *i* is shown as follows:

$$q^i = exp\left[-n\frac{f(x^i)-f(x^{best})}{\sum_{k=1}^{m} f(x^k)-f(x^{best})}\right], \forall i \qquad (1)$$

where q^i is the charge of particle i, $f(x^i))$, $f(x^{best})$ and $f(x^k)$ denote the objective value of particle i, the best solution and particle k. Finally, m is the population size.

The solution quality or charge of each particle determines the magnitude of an attraction and repulsion effect in the population. A better solution encourages other particles to converge to attractive valleys while a bad solution discourages particles to move toward this region. These particles move along with the total force and so diversified solutions are generated. The following formulation is the force of particle i.'

$$F^i = \sum_{j \neq i}^{m} \begin{Bmatrix} (x^j - x^i)\frac{q^i q^j}{\|x^j - x^i\|^2} & if\ f(x^j) < f(x^i) \\ (x^i - x^j)\frac{q^i q^j}{\|x^j - x^i\|^2} & else\ f(x^j) \geq f(x^i) \end{Bmatrix}, \forall i \qquad (2)$$

The fundamental procedures of EM include initialize, local search, calculating total force and moving particles. The generic pseudo-code for the EM is as follows:

Algorithm 1. EM ()

```
initialize()
while (hasn't met stop criterion) do
    localSearch()
    calculate total force F()
    move particle by F()
    evaluate particles()
End While
```

Proposed Approach: In this section, we present our proposed approach The Fig.1 represents the overview of proposed system.. We first present the network assumptions and coverage model and then we discuss the hybrid approach.

Network Assumptions: It was assumed that the sensor nodes are randomly deployed and equipped with GPS and the base station node position is stationary. Furthermore, the number of sensor nodes that are initially deployed equals the number of nodes that are required to achieve full coverage as if these nodes were deterministically deployed. It was also assumed that few mobile nodes are available and can be used to repair the coverage holes after initial deployment of the stationary nodes.

Coverage Model and Hole Detection: We assumed that each sensor node with a sensing radius *r* can cover an area of circular shape. We also assumed that a Point P_j can be detected by sensor S_i if P_j is within the sensing range of S_i. This can be represented using the binary model of sensor detection which is given by

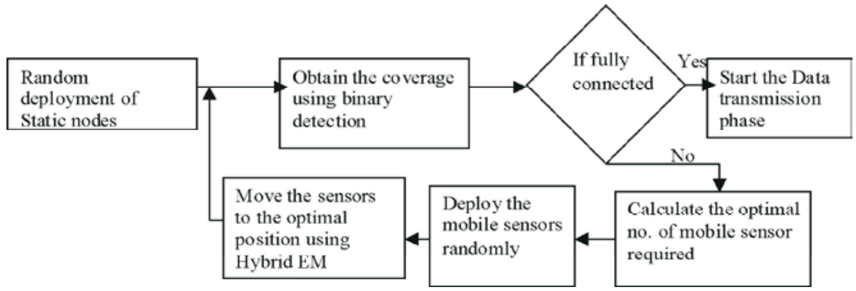

Fig. 1: Overall view of Proposed System

$$Coverage(S) = f(x) = \begin{cases} 1, & D(S_i, P_j) \le r \\ 0, & D(S_i, P_j) > r \end{cases} \quad (3)$$

where D is the distance between the point being sensed P_j and the sensor node Si. The coverage function Coverage(S) equals 1 when the target object can be covered or sensed, otherwise it equals 0. If all the points within the deployment are covered by at least one node then the network is fully connected network. Otherwise we need to deploy additional mobile sensors to increase the coverage.

Hybrid Approach for Mobile Sensor Deployment: The hybrid framework includes modified EM procedures and genetic operators, which adopts selection and mating. The selection operator is binary tournament and uniform crossover operator is applied in the framework. Generic EM provides an excellent diversity while GA is able to converge to a better solution quickly. Thus the hybrid method takes the advantage of both sides. The hybrid system starts with determining which particle is moved by EM or mated by GA crossover operator. The new solution can be obtained from crossing between a better solutions selected by a binary tournament method. And EM is used to move the inferior solution to a new position. This hybrid approach may encourage solutions converging toward better region quickly and to prevent from trapping into local optima by maintaining the population diversity. Algorithm 2 is the pseudo code of the main procedures of the hybrid framework. The Algorithm.3 presents our proposed approach.

Algorithm 2. A Hybrid Framework

Initialize ()
while (hasn't met stop criterion) do
  local_Search()
  avg ← calc_AvgObjectiveValues()
  for i = 1 to m do
    if ((i ≠ best) and(f(xi) < avg) then
      j ← a selected particle to mate particle i by binary tournament()
      uniform_Crossover(xi, x j)
    else if (f(xi) > avg) then
      CalcForce() and Move(xi)
    end if
  end for
  evaluate particles()
end while

Algorithm 3. A Hybrid Framework

Initialize the Required Parameter: sensor detection radius *r*, communication range of the sensors *comr*, the size of the coverage area *A*, the number of static sensors Ns, Number of mobile sensors Nm, dimension of the population *n* parameter of GA crossover rate *crrate*, mutation rate *murate*, the maximum number of *maxiteration* iteration iteration are initialized

Deploy the Static Sensors Randomly: Calculate the coverage ratio of static deployed nodes using (3) and find the optimum number of mobile sensors required to get the full coverage.Initialize random locations for the deployment of mobile sensors.

Deploy the Mobile Sensors Randomly Using:
  for t1=1 to m do
    for t2=1 to n do
      λ<Uniform(0,1)
      $x_k^i \leftarrow l_k + \lambda \times (u_k - l_k)$
    end for
end for

(4) *while iter ⇐ maxiteration*

Calculate the Objective Function (*fx*) Values of the Sensors: In order to calculate the charges of the sensors which are deployed in the solution space randomly according to the particle model in the EM algorithm, the objective function value of each sensor is calculated based on their existing positions as follows:

$$f(x^i) = \sum_{k=1}^{n} x_k^i (u_k - l_k), i = 1,2 \dots \dots, m$$

where *f*(*xi*) is the objective function value of sensor *i*, x_k^i is the coordinate value in the k^{th} dimension of the sensor *i*.

Calculate Charge of the Sensors: Sensors used in the network are assumed as a charged particle in the solution of the dynamic deployment problem. In order to calculate attraction-repulsion forces between the sensors based on the particle model of the EM algorithm which is expressed by Algorithm 1, the charge values of each sensor *qi* are calculated using (1).

Detect the Optimal Distributed Mobile Sensors: Sensors which have been placed in optimal locations are detected with the help (3)

Calculate the Resultant Force of Non-Optimal Sensors: A resultant force, *fi*, which is calculated according to (2) by adding up the forces applied by the other sensors in the area to each sensor, is not optimal as a result of not being able to be placed in an optimal location, is applied to the non-optimal sensors. There is no need to calculate the resultant forces of optimal sensors. Because as it is stated on the next step, the 9th step, once and the sensors are placed on optimal locations, their placements will not be changed so on.

Update the Locations of Non-Optimal Sensors: Each non-optimal sensor in the area updates its current location according to Algorithm 2 by moving in the direction of the resultant force applied on it.

iter = iter +1
end while

Performance Evaluation: In this section, the performance of the proposed hybrid algorithm is evaluated in terms of the amount of coverage (coverage ratio), degree of coverage (k-coverage) and number of additional mobile nodes. Moreover, the effect of the number of randomly deployed static nodes and the sensing ranges on coverage and number of additional mobile nodes were investigated. In the simulation environment, it was assumed that the sensor nodes were randomly deployed in 200m × 200m sensor field. The number of static nodes deployed is set to 100. For the experiments the number of deployed mobile nodes is fixed to 30, while the sensing ranges vary from 10m to 20m. In the second experimentthe number of mobile node varies from 30 to 50. In each experiment, the coverage ratio, k-coverage was measured before and after applying the proposed algorithm. Also the results were compared with pure genetic algorithm based node deployment, results shows the hybrid algorithm performs better than the existing one.

Effect of Sensing Range: Figure 2 shows the coverage ratio when the static nodes are randomly deployed and after adding 30 mobile nodes as a function of the sensing ranges. It is shown that the coverage ratio increases as the sensing radius of the deployed nodes increases.

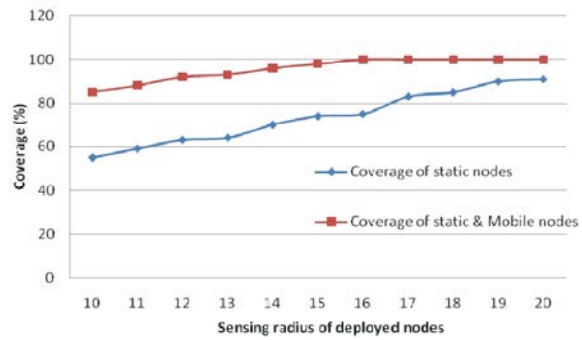

Fig. 2: Coverage ratio of different sensing ranges

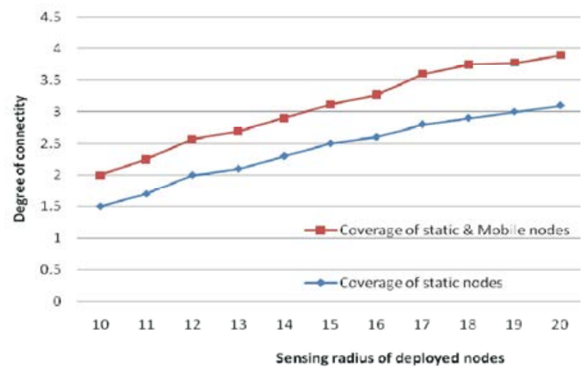

Fig. 3: Coverage ratio of different sensing ranges

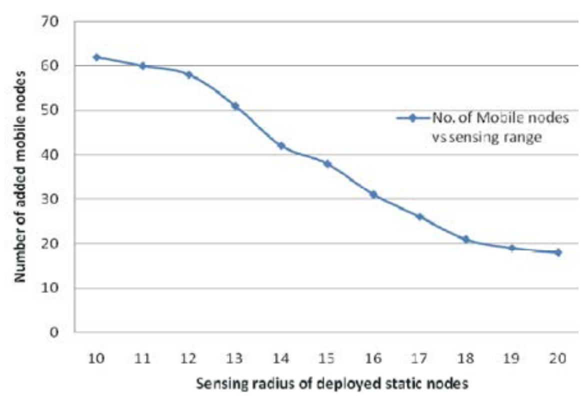

Fig. 4: Coverage ratio of different sensing ranges

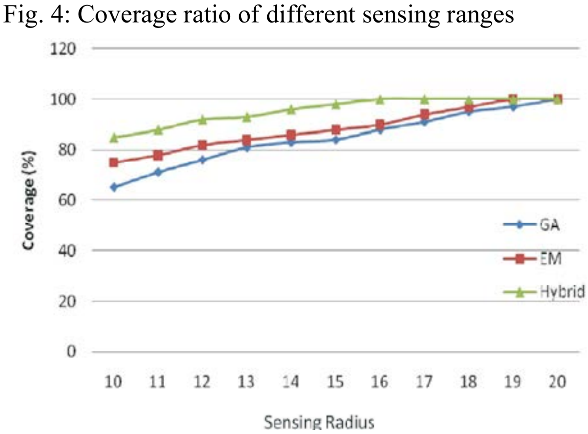

Fig. 5: Performance of Hybrid scheme

Figure 3 shows the k-coverage when the static nodes are randomly deployed and after adding the 30 mobile nodes as a function of the sensing ranges. As shown, the k- coverage increases as the sensing radii of the deployed nodes increase. This is because the coverage among sensor nodes with large sensing range is very likely to overlap and hence more targets would be covered by multiple nodes.

Figure 4 shows the number of additional mobile nodes as a function of the sensing range. It is shown that the number of mobile nodes decreases as the sensing radii of the nodes increase. This is because more targets would be covered as the sensing range of the static nodes increases and hence less mobile nodes would be added to increase the coverage ratio.

Figure 5 shows the performance of EM algorithm, Genetic algorithm and hybrid approach in terms of coverage ratio. The figure shows clearly that the hybrid approach outperforms the case of random deployment of the static nodes as the additional mobile nodes are located into regions where targets are not covered by the static nodes.

CONCLUSION

This paper presents a hybrid framework to find an optimal solution to the coverage holes problem caused by random deployment of stationary sensor nodes in wireless sensor network. The coverage holes are detected by binary detection and they are healed by adding mobile sensors with the existing stationary sensors. The performance of the algorithm was evaluated in terms of the coverage ratio, k-coverage and the number of additional mobile nodes requires for various sensing ranges. The results are also compared with the existing algorithms like EM and GA. The simulation results showed that the hybrid algorithm can maximize the coverage of the sensing field by finding the minimum number of additional mobile nodes and their best positions in the field.

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