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GRID BASED WIRELESS MOBILE SENSOR NETWORK DEPLOYMENT WITH OBSTACLE ADAPTABILITY

Mr. Mayur C. Akewar[1] and Dr. Nileshsingh V. Thakur[2]

[1]Department of Computer Science & Engineering, Shri Ramdeobaba College of Engineering and Management, Nagpur University, Nagpur, India
mayurakewar12@gmail.com
[2]Department of Computer Science & Engineering, Shri Ramdeobaba College of Engineering and Management, Nagpur University, Nagpur, India
thakurnisvis@rediffmail.com

ABSTRACT

Mobile Sensors find their target position and placed themselves over the target field to achieve a certain goal in self deployment with certain additional functionality like sensor relocation. An efficient deployment scheme guaranteed maximum coverage with full connectivity. Certain variance of coverage could be manageable but loss of connectivity because of failure of some sensor node causes complete isolation of some sensing area which causes loss of data of that area. So it is not enough to be just connected, it should be K connected (K>1) to control the isolation. Again the obstacles over the target field should be managed during deployment. A self deployment scheme using mobile sensors is proposed which achieve K connectivity. The target area is divided into n × n square grid. The distributed algorithm deploys a sensor in each square grid cell to maximize the coverage and achieve K connectivity. A square grid deployment pattern is used which guarantee at least (K=4) connectivity. The first algorithm assumed a plane target area with no obstacle. The second proposed algorithm has the capacity of obstacle adaptability which assumed a target area with some obstacle. Simulation result shows maximum coverage with minimum moving cost and obstacle adaptability.

KEYWORDS

Wireless Sensor Network, Wireless Network, Mobile Sensor Network, Coverage, Connectivity, Movement Cost, Obstacle Adaptability

1. INTRODUCTION

Wireless Sensor Network (WSN) has emerged as an efficient technology for wide variety of applications such as home automation, military application, environmental monitoring, habitat monitoring etc. It consists of distributed autonomous sensors to monitor physical or environmental conditions and to corporately pass their data through the network to main location. Sensor nodes are severely constrained in terms of storage resources, computational capabilities, communication bandwidth and power supply. WSN face many challenges due to these many constraints such as life of network, efficiency and the performance of network. An efficient deployment technique handles these challenges. Deployment is very critical issue because it decides the performance of wireless sensor network. Given set of sensors are deployed with a goal of maximizing the area that covered by the sensors. The deployment can be deterministic [1] or random [11] or incremental [2] or self deployment [4-6], [8], [12], [13], [15]. In this paper, following self deployment problem has been considered: *"Given a target sensing field with an arbitrary initial sensor distribution, how should these sensors self organize into a*

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connected ad hoc network that has the maximum coverage, at the cost of a minimum moving distance?"

Uniform distribution of sensor nodes over the target field is very important to cover maximum area. For uniform distribution the node has the additional capability of locomotion such that the sensor moves from high dense area to low dense area. After random deployment, the node self deploy themselves to achieve uniform distribution. Node find its own location and self deploy it to desired location with the capability of mobility. With the help of self deployment the sensor relocate them to the low dense area to achieve maximum coverage. Self deployment is very efficient form of deployment to manage the network dynamics. Self deployment uses mobile sensors for placement of sensor node. Mobility includes different functionality in wireless sensor network like coverage optimization, better lifetime of network, better use of resources and relocation [4]. Sensor nodes may change their location after initial deployment. Mobility may apply to all nodes or only to subsets of nodes. M. Marks [26] give taxonomy of mobility. Mobility may be active or passive. In active mobility the sensors are intelligent enough to find their path and move while in passive mobility the sensors may move by human or environmental assistance. J. Luo and et al [24] defined two types of mobility; they are U- mobility and C- mobility called as double mobility. C- mobility is controllable while U- mobility is uncontrollable. C- mobility is the property of sensor node and U- mobility is affected by environmental condition like wind. Mobility is essential for self deployment [4], [5], [6], [8], [12], [13], [15], that is to find the position and move to deploy them. Two mobile sensor platforms Racemote [9] and Robomote [22] are used for mobile sensor network deployment. A wireless mobile sensor network deployment approach is proposed by handling the issues of coverage, connectivity and movement cost of sensor node.

In this paper, distributed algorithm which solve the above problems has been proposed and get the K connected deployment scheme after random deployment. The proposed approach used square deployment pattern for at least K=2 coverage and at most K=4. The sensor nodes should self deployed them after initial distribution of sensor nodes on the target area. We consider a square target area and divided it into square grids. After random deployment the sensor should self deploy them such that each grid cell has exactly one node and each node should connect with at least 2 sensor nodes. We try to reduce the communication overhead to only communicate the sensor nodes within the grid cell and also to reduce the movements of sensor nodes to save the energy which results in increasing network lifetime. The first algorithm assumed a plane target area with no obstacle. In most of the existing work researcher assumed a target field with no obstacle. The second proposed algorithm has the capacity of obstacle adaptability which assumed a target area with some obstacle. The proposed algorithm achieved a self deployment of sensors with minimum moving cost of sensors for minimizing energy consumption with obstacle adaptability. Simulation result shows maximum coverage with minimum moving cost and obstacle adaptability.

This paper is organized as follows: Section 2 gives the related work. Section 3 gives the preliminaries of the system. Section 4 gives the proposed scheme. Section 5 gives experimental results. The paper ends with conclusion and future work which is given in section 6.

2. RELATED WORK

Different approaches have been proposed for the deployment of mobile sensor for solving above problem. Some proposed approaches used virtual force [27] and [29] approach which considered the mobile nodes as a particle under attractive or repulsive force. The sensor nodes modelled as points subject to attractive or repulsive force according to the distance between two sensors. The virtual force exerted on the sensor is similar to the Coulomb force. By setting the threshold distance between sensors, each sensor moves in accordance with the summation of the force vectors and eventually a uniform deployment is achieved. The potential force [4] based method which used the method to migrate the node from high density to low density area.

Computational Geometry based approach which used the popular data structure Voronoi diagram has been proposed in [27]. According to F. Aurenhammer [30], it is believed that the Voronoi diagram is a fundamental construct defined by a discrete set of points. Voronoi diagram is used to discover the e Voronoi diagram is constructed on the basis of neighbors who are in the communication range. If there is less number of nodes in the communication range it will result in improper voronoi diagram construction. Second problem with this approach is that we will not get optimal deployment. Again existing approaches have the problem of optimal deployment and high communication overhead to communicate to construct the voronoi diagram or to calculate the virtual forces. There is chance of unnecessary movements of nodes in the existing approaches. Most of the existing studies mainly considered the issue of coverage, but sensor network is often gets into sensor failure so the sensor should be at least K connected with K>1. Existence of coverage hole once all the sensors have been initially randomly deployed in the target area. A node needs to know the location of the neighbors to construct the voronoi diagrams. The diagram partition the whole target area into voronoi polygons. Each polygon has a single node with the property that every point in this polygon is closer to this node to estimate any local coverage hole. After each iteration, every sensor node moves to an improved location and then the voronoi diagrams are reconstructed. Another structure that is directly related to Voronoi diagrams is the Delaunay triangulation [29], [13]. The Delaunay triangulation can be obtained by connecting the sites in the Voronoi diagram whose polygons share a common edge. It has been shown that among all possible triangulations, the Delaunay triangulation maximizes the smallest angle in each triangle. N. Azlina and *et al* [8] proposed coverage optimization algorithm based on particle swarm optimization (PSO). C. Hsien and *et al* [13] and S. Megerian and *et al* [14] proposed Delaunay triangle based approach. The algorithm eliminates the coverage holes near the boundary of sensing area and obstacles Delaunay triangle is applied for the uncovered regions. G. Tan and *et al* [6] proposed enhanced form of Virtual force method called as connectivity preserved virtual force method (CPVF). The authors consider the obstacles during deployment. The given approach is used for mobile sensor network for the self deployment. The authors overcome the limitations of previous approaches where large communication range, dense network and obstacle free field or full knowledge of the field layout have been assumed. M. Garetto [15] proposed a virtual force method used for sensor relocation. Upon occurrence of physical phenomenon nodes relocate themselves so as to control the event, while maintaining network connectivity. After event ends all nodes return to the monitoring configuration. J. Lee and *et al* [4] proposed a potential field based approach. After initial deployment, group of mobile sensor clusters are formed using potential field method and then cluster heads are used to establish hexagonal structure or achieving coverage. L. Filipe and *et al* [2] proposed an efficient incremental deployment algorithm using Largest Empty Circle problem. Algorithm indicates position for new nodes to be deployed and number of new nodes. A network is said to have k-coverage if every point in it is covered by at least k sensors. the k-coverage map for a square grid and THT. S. Shakkottai and *et al* [18] proposed unreliable sensor grids by considering issue of coverage and connectivity. X. Bai and *et al* [20] investigate different deployment models with their performance evaluation. B. Liu and *et al* [21] discuss he question "Is mobility improves coverage of sensor network?". S. Yang and *et al* [23] proposed scan based movement assisted deployment method. By handling the issue of coverage an algorithm named SMART (Scan based movement assisted) is proposed. A unique problem called communication hole is handled here. The algorithm control the moving distance. G. Wang and G. Cao [27] proposed Coverage hole detection method. A robot deployment algorithm that overcomes obstacle and employs full coverage with minimal number of sensor node is discussed in [10]. A mobile Robot is used for placing sensors. The robot explores the environment and deploys a stationary sensor to the target location from time to time.

Non uniform sensor deployment in mobile sensor network is discussed in [16]. A Jagga and *et. al.* [31] proposed an approach for deploying mobile agents. G. Wang and *et. al.* [32] proposed an approach for dynamic deployment by using both static and dynamic sensor nodes.

Most of the work evaluates the performance of the network on the basis of coverage and number of sensors. Use of mobility for sensor relocation to improve coverage, and network lifetime after failure of some nodes in the system has proposed in some work. Constrained coverage approach for better network performance and energy efficiency has been proposed in some work. Balancing energy consumption by placing sensors in terms of different densities (non uniform deployment) is proposed. Computational geometry data structure like voronoi diagram and Delaunay tringulation is used for finding coverage hole is proposed in most of the work. Virtual force method and movement assisted method is used for movement of sensors in most of the work. Coverage is an open issue which can be handled in most of the approach. Sensor movement also need energy, so cost of sensor movement should be minimized. Efficient management of mobility towards a better coverage remains an unanswered question.

We are using a square deployment pattern and a grid based approach such that we can manage the mobility of the sensor node efficiently. The cost of the movement is minimized considerably in our proposed approach. We achieved nearly hundred percent coverage with maximum K=4 connectivity. So our approach is different from existing approach such that we achieve both maximum coverage and K connectivity with minimum movement cost. Also the obstacle over the target field is handled in a better way.

3. PRELIMINARIES

3.1. System Assumptions

We assume that the target area is on a 2D plane. We assume that all the sensor nodes are homogenous with same sensing and communication range. Both ranges are assumed as disk based model. If the two sensors are in range then they are called as neighbors. A sensor can determine the position of other sensor only by communication. The sensing range R_s is equal to $\sqrt{2}$ × the length of the side of square grid to achieve optimal coverage and communication range R_c is equal to $\sqrt{2} \times R_s$ to have a connected network. Each sensor node knows the coordinates of their position by using some localization technique like GPS. Sensor nodes should be able to change their position coordinates after each movement. We may use a mobile sensor node platform Robomote [28] and Racemote [9]. Each sensor node knows the dimension of square target area, also each sensor node knows the dimension of square grid which is fixed for each cell and should be able to get the centre coordinates of the square cell where it is currently deployed. Sensor node moves with uniform speed horizontally or vertically in a straight line for fixed amount of time which we called as time.

3.2. Target Field

We are using a square target field on 2D plane surface. The target field is divided into equal size square grid cell. The field is divided into 3 × 3 grid. Each cell has given a cell id, starting from left upper corner. Cell id’s are from 1 to 9.

3.3. Deployment Pattern for Achieving K Connectivity

We have divided the target area into equal length square grids cell to achieve optimal coverage and K connectivity. Reason of using an optimal deployment pattern [1] is that the sensor network could subject to failures, so the sensor node should at least K connected (K>1). If anyone node failed, then other node could serve the purpose. A square grid provides at least 4- connectivity [6]. When $1.14 \le R_c/R_s \le \sqrt{2}$, the square pattern is better than other deployment pattern [6]. We are assuming the sensing and communication range within the above range.

3.4. Information to Each Sensor

Each sensor knows the dimension of target field and the grid cell. Position of the sensor node is known with the help of GPS device. Also the node should get the centre of cell by using its position coordinates. Each cell only communicates to other node within its own cell. Each sensor node has a list of the connected nodes within the cell. By which the nodes within the cell decides the next action by local communication. Each senor node has a list of closest boundary distance and its direction to decide the next move. Each node has an energy counter which is decremented after each movement to calculate the movement cost of the sensor. Each sensor node should move until the goal is reached or to a fixed amount of distance and decides the next action. Each sensor should identify the boundary of the obstacle. After identification of obstacle boundary the sensor node should move towards next closest boundary. Each node has a counter for time which set to some threshold value. After random deployment the node starts the timer and wait up to set threshold value. If it migrate to another cell then the timer again set to zero and again start the timer until another event is occur or to a threshold time. Each cell node has a cell id for identification of the cell in which it is currently deployed. The cell cannot return to the previous cell by searching the cell id list.

3.5. Movement of Sensor Node

Each sensor node moves for a fixed amount of time and distance in horizontal or vertical direction. After each move the energy is lost which is represented by an energy counter set to some value. For minimizing the movement cost the sensor node with maximum energy will move and the sensor node with minimum energy stays in the cell. Also the sensor will move towards closest boundary to minimize the movement cost. The sensor node cannot move to the same cell again by looking at the cell id list. For this, each sensor node has the history of cell id.

4. PROPOSED APPROACH

4.1. Problem Definition

Given a target sensing field with an arbitrary initial sensor distribution, these sensors should self organize into a k-connected ad hoc network that has the maximum coverage, at the cost of a minimum moving distance.

In the initial phase, the target area is divided into n × n equal square grids and the R_S, R_C values are decided on the basis of length of the side of the grid cell. R_S=√2× side of the cell and R_C=√2 ×R_S. The sensor nodes are fixed which is equal to number of cells. If there are 9 cells then the nodes are also 9. The sensor nodes are randomly deployed on the target field. A distributed algorithm is executed in each sensor node to self deploy the sensor node such that each cell reach the center of the grid to achieve optimal deployment. The proposed approach gives maximum coverage with minimum moving distance and obstacle adaptability.

4.2. Scenario 1

If after random deployment, each cell has exactly one sensor node then the self deployment is quite simple. The list of connected nodes is empty. So the sensor node decides that my cell does not contain any other node, so the there has not any redundant node for migration or relocation. The sensor node knows the center of the current deployed cell, so the particular sensor just has to move to the center of the cell. Each sensor node will performed following steps.

1. All the nodes broadcast hello message with their position coordinates and wait for acknowledgement and start the timer.
2. If the node j present in the same cell then from position coordinates it will decides that the node i is in its own cell, it send acknowledgement message and they will connect if distance (i, j)<=Rc.
3. If the node does not receive any acknowledgement means the cell contains only one node
4. After timer reaches a threshold value the node stop waiting and it will then execute the MovetoCenter Algorithm to reach to center of cell.

MovetoCenter algorithm is given below. Consider that a sensor node has the coordinate value Xnode and Ynode. The sensor will move until it reach the center of the cell to maximize the coverage, that is (Xnode, Ynode)=(Xcenter, Ycenter), where Xcenter and Ycenter are the x coordinate and y coordinate of center of a cell.

Algorithm

```
do{
If (Xnode< =Xcentre) && (Ynode<=Ycentre)
{Xnode=Xnode+(Xcentre, Xnode);Moveto(Xnode, Ynode);
Ynode= Ynode+(Ycentre- Ynode);Moveto(Xnode, Ynode);
Else If (Xnode< =Xcentre) && (Ynode>=Ycentre)
{Xnode=Xnode+(Xcentre-Xnode); Moveto(Xnode, Ynode);
Ynode= Ynode-(Ynode- Ycentre); Moveto(Xnode, Ynode);}
Else If (Xnode>=Xcentre) && (Ynode>=Ycentre)
{Xnode=Xnode-(Xnode-Xcentre); Moveto(Xnode, Ynode);
Ynode= Ynode-(Ynode- Ycentre); Moveto(Xnode, Ynode);}
Else If (Xnode> =Xcentre) && (Ynode=<Ycentre)
{ Xnode=Xnode-(Xnode-Xcentre); Moveto(Xnode, Ynode);
Ynode= Ynode+(Ycentre- Ynode); Moveto(Xnode, Ynode);}
}while((Xnode, Ynode)==(Xcenter, Ycenter));
```

4.2.1. Execution of Scenario 1

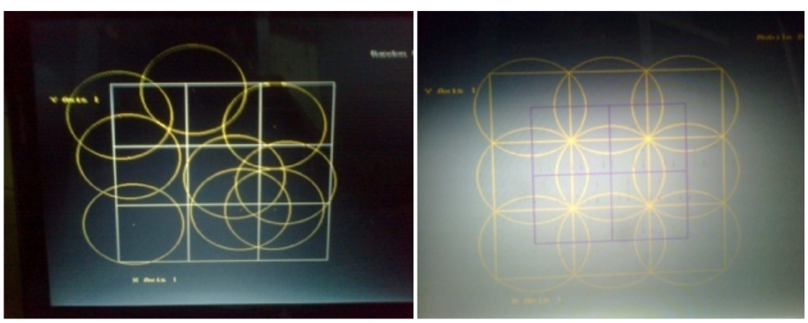

Figure 1 Initial and Final Deployment

4.3. Scenario 2

After random deployment if there is more than one sensor is deployed in a cell then it will follow following strategy.

a) Identifying Redundant Node: If a cell contains more than one node after initial distribution then each node has to decide the nodes which are redundant. The redundant nodes migrated to other cell which is close to it. Foe identification of redundant nodes, we use some distance measures. For each cell we have decide a fixed location. The distance between that location and the location of node is calculated. The node with minimum distance stayed in the cell and the other node will move towards the closest boundary until they will migrate to new cell. If any cell has only one node then that node will move to a threshold distance such that if another node comes then it should be connected to that node.

b) Movement of Node: The redundant nodes will move towards closest boundary until migrated to new cell and updated their position coordinates. The direction for movement is towards closest boundary. If the closest cell is the cell from where the node was coming, in such a case the node will move towards the next closest boundary. For this purpose the node look at the history of cell id.

c) Minimize movement cost: Each sensor node has two counter one is timer‘t’ and other is migration counter ‘m’, each one is set to zero. If there is only one node within a given cell then the counter t is started until a threshold time. After that time is reached then the sensor decides that know sensor is migrated in its cell then the node will follow my MovetoCenter algorithm to move to the center. If a node is migrated then the other node and the migrated node set t=0 and decides the next move by communication. The migrated node increment the counter to 1 and push the other node to migrate to other cell which is depends upon the distance between the boundary and the location of the sensor. If there is a tie then the sensor node with maximum distance from center to its location moves and other stays. After each communication within the cell the node set the timer to t=0. The nodes which are deployed on the boundary cell are quite intelligent to decide not to move towards the boundary of the target field.

4.3.1. Steps for Scenario 2

1. All the sensor nodes broadcast hello message with their position coordinates and wait for acknowledgement and start the timer.
2. If the nodes gets acknowledgement then the cell contains more than one node and they update their connected node list.
3. If the nodes does not get any acknowledgement means the node is isolated, then the nodes will move towards center until it is connected or reach a threshold distance.
4. The nodes calculate the distance from a fixed location which is depends upon the cell.
5. The nodes share their distance list through local communication to all the nodes in the given cell.
6. The node compares the distance.
7. The node with maximum or minimum distance (which is depends upon the cell) stay in the cell and the other (redundant sensors nodes) migrated to nearest cell and increment the migration counter, and update cell id and position coordinates. If the nearest cell has already visited then the sensor node will move towards the next nearest cell.
7. After migration the timer again set to zero and the node waits for local communication by sending hello message in some time interval.
8. If the migrated sensor node receives acknowledgement then it will repeat step 4 to 7.
9. If two sensor nodes has same migration counter then the nods which will migrated is decides on the basis of energy level. The node with high energy will migrate.
10. If the node has to move to the same cell again, then from cell id it will decides not to move to that cell. It then migrated to the next closest boundary.
11. If each cell contains exactly one node and timer=threshold time then the MovetoCenter algorithm will execute.

4.3.2. Execution of Scenario 2

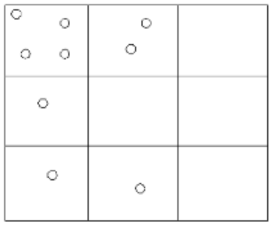

Figure 2 Initial Phase

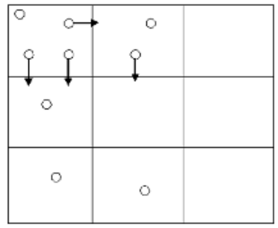

Figure 3 Iteration 1

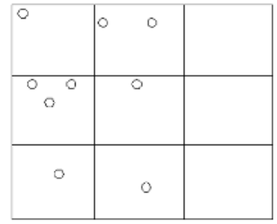

Figure 4 Iteration 2

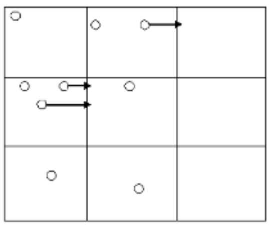

Figure 5 Iteration 3

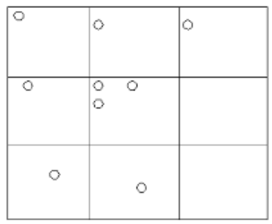

Figure 6 Iteration 4

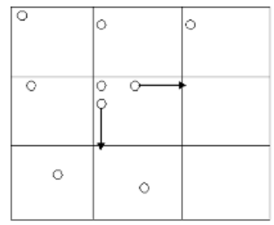

Figure 7 Iteration 5

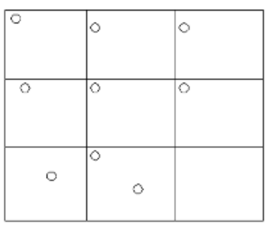

Figure 8 Iteration 6

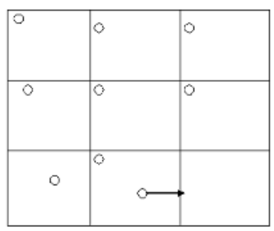

Figure 9 Iteration 7

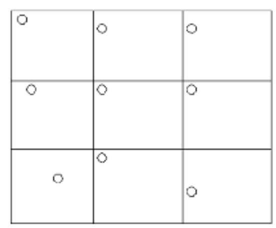

Figure 10 Iteration 8

4.4. Scenario 3

The target field contains any obstacle. Our previous algorithm will oscillate because at any given time the condition of all the cell contains exactly one node cannot satisfy.

4.4.1. Obstacle Adaptability

Sensor node knows the boundary of obstacle. During movement of sensor node if any obstacle arrives in the path of sensor node, then the sensor node will turn and move towards the next closest boundary. For achieving stability we set the migration counter to a threshold value and execute the previous algorithm. The sensor migrated only for the fixed count. If the migration count is equal to one then the node will migrate only once.

We are assuming that a cell is totally covered by an obstacle. So during movement of sensor, if the closest boundary is towards obstacle covered cell, then the sensor node will unable to move or migrate to that cell, so the node calculates the next closest boundary and move towards that cell.

We are considering that the obstacle is in center cell as shown in figure. After execution of the algorithm any cell contains more than one node. In such a case the sensor node with maximum energy will executes the MovetoCenter algorithm while the other node will go to the sleep mode, which could be used for the incremental deployment if the node in the cell has failed.

Figure shows the movement of sensor if any obstacle comes in the path of sensor node.

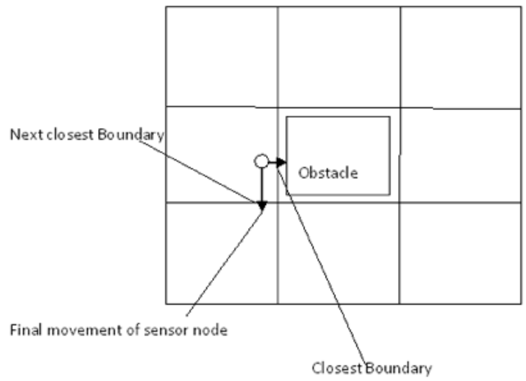

Figure 11 Obstacle Adaptability

4.4.2. Execution of Scenario 3

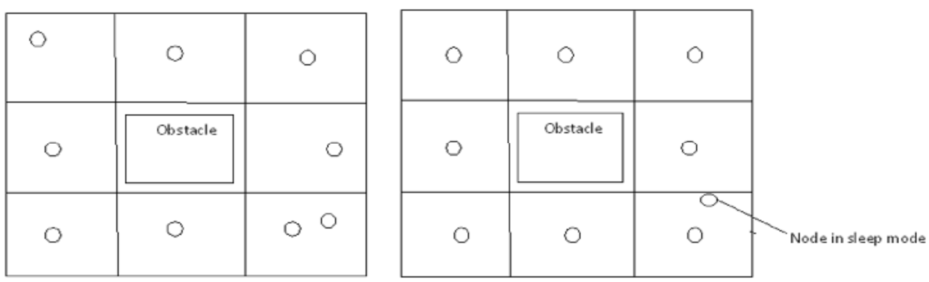

Figure 12 Initial and Final Configuration

5. EXPERIMENTAL RESULTS

We have used a ‘C’ based simulator for simulating the above mobile deployment scheme. We have considered a 3×3 grid square target field (300 × 300 meter square) with 9 sensors such as each cell must have 1 node deployed. Each cell has a area of 100 ×100 meter square. Sensing range is decided as Rs=71 meter and communication range as Rc=101 meter. Energy counter is initialized as 2000 and migration counter is initialized as m=0. The target area is fully covered with at most K=4 connected sensor node. The performance graph shows the energy lost during movement for various scenarios.

5.1. Execution 1

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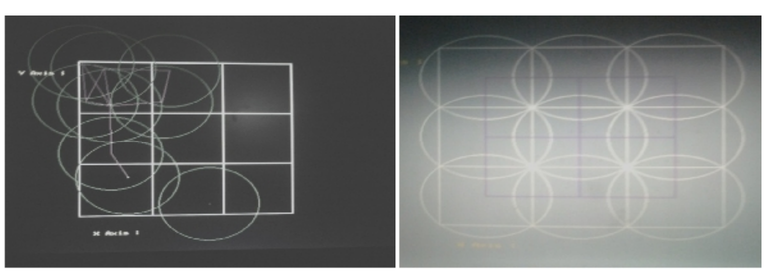

Figure 13 Initial and Final Configuration

Initially the field does not contain any obstacle. The surface is flat. Figure shows the initial configuration after random deployment. The distributed algorithm is executed and the final configuration is achieved with 100% coverage and at most K=4 connectivity. The performance graph shows the movement cost during deployment of the sensors. The circle shows the sensing range and the connectivity is shown by lines.

5.1.1. Performance Graph of Eecution 1

Graph shows the enegy lost during sensor movement.

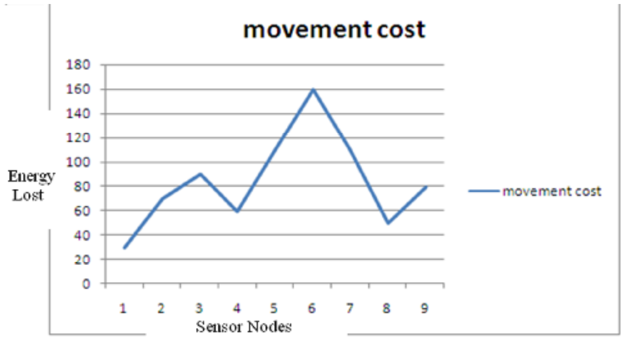

Figure 14 Cost of Node Movement

5.2. Execution 2

The target field contains obstacle. Figure shows the initial configuration after random deployment. The performance graph shows the movement cost during deployment of the sensors. The circle shows the sensing range. The middle cell contains obstacle.

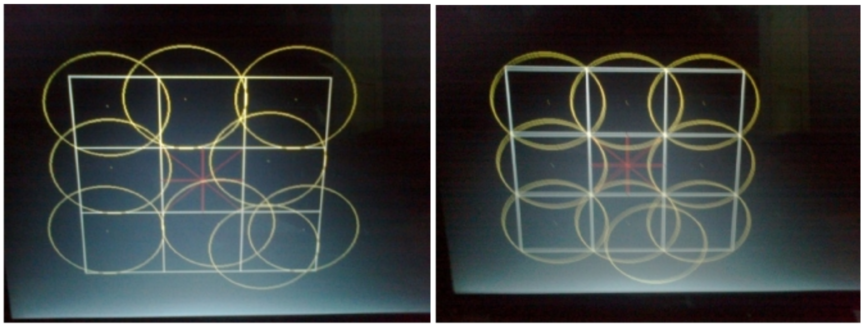

Figure 15 Initial and Final Configuration with Obstacle

5.2.1. Performance Graph of Execution 2

The graph shows the energy lost during movement of sensors. Performance is evaluated by considering different migration count. We are considering maximum migration count m=4.

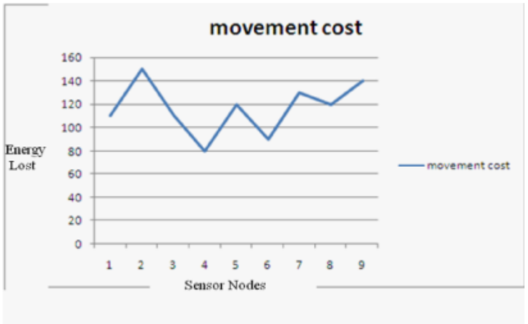

Figure 16 migration count=1

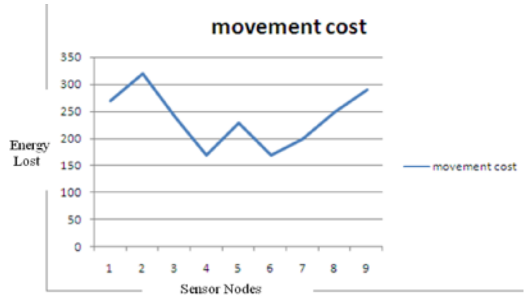

Figure 17 migration count=2

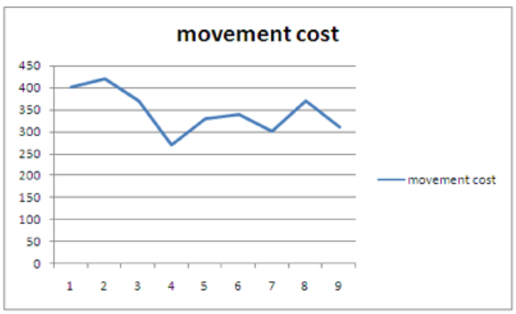

Figure 18 migration count=3

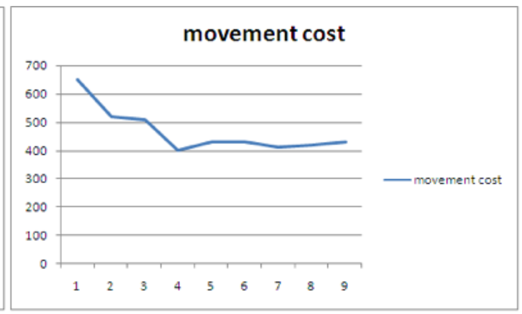

Figure 19 Migration count =4

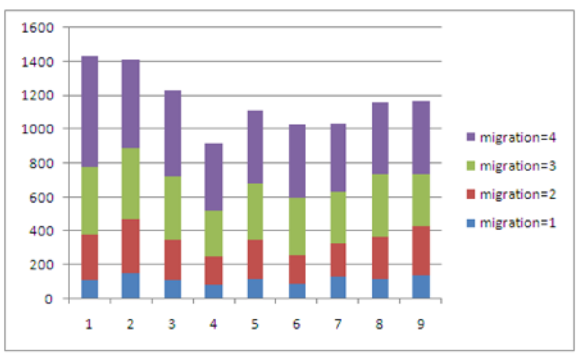

Figure 20 Energy lost for various migration counts

6. Conclusion and Future Work

We proposed a grid based mobile deployment algorithm which self deploy the fixed number of nodes in each grid cell. The distributed algorithm is efficient to minimize the cost of movement and communication overhead. The square deployment pattern has at least 4-connectivity and coverage. In future work we can have more experiments on the obstacle avoidance strategy while deployment by considering obstacles at different position on the target area and measure the energy lost by setting the migration counter. We can use this 3×3 grid as a mask for a larger target area and large amount of sensor nodes. Also different deployment patterns like hexagonal and triangular pattern can be used for self deployment scheme.

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Authors

Mayur Akewar received the Bachelor of Engineering degree in Computer Technology from Karmvir Dadasaheb Kannamwar College of Engineering, Nagpur, India in 2010. Presently he is pursuing his PG (M.Tech) in Computer Science and Engineering from Shri Ramdeobaba College of Engineering & Management, Nagpur, India. His research interest includes Wireless Sensor Network . He is a life member of ISTE New Delhi India.

Dr. Nileshsingh V. Thakur received Bachelor of Engineering degree in Computer Science Engineering from Government College of Engineering, Amravati, India and Master of Engineering degree from College of Engineering, Badnera under Amravati University and Sant Gadge Baba Amravati University in 1992 and 2005 respectively. He received Ph.D. degree in Computer Science Engineering under Department of computer Science Engineering from Visvesvaraya National Institute of Technology, Nagpur, India on 1st February, 2010. His research interest includes image processing, sensor network, computer vision, pattern recognition, artificial neural network and evolutionary approaches. He is having over 20 years of teaching and research experience. Presently, he is Associate Professor in Department of Computer Science and Engineering at Shri Ramdeobaba College of Engineering and Management, Nagpur, India. He is the author or co-author of more than 40 scientific publications in International Journal, International Conferences and National Conferences. Dr. Thakur is a member of editorial board of over eight International journals; also, he is the life member of ISTE, India, IAENG and IAEME. He also worked as the reviewer for international journals and conferences.