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Enhancing Coverage Ratio using Mobility in Heterogeneous Wireless Sensor Network

Durga Pavan Nudurupati[a], Rajat Kumar Singh[a,]*

[a]*Indian Institute of Information Technology, Allahabad, 211012, India*

Abstract

In the lifespan of the sensor network, coverage, localization, reliability and lifetime (when the final sensor dies) are the major design challenges for which the work is still going on. Especially in heterogeneous wireless sensor network, it is very difficult to estimate the coverage and lifetime of the network. There have been many existing classical protocols in heterogeneous network where the heterogeneity was taken either in sensing radius or in the energies of nodes. An idea to increase the coverage ratio as well as the lifetime of the senor network is suggested in this paper by introducing mobility in heterogeneous WSN, where the heterogeneity is considered in energy of nodes. We have chosen the deployment in heterogeneous wireless sensor network with loco-mobility capability nodes which has different energies. The simulation results show that in our algorithm, maximum area is covered, and in addition, some nodes are in off state to conserve the energy. We consider the nodes to cover large area while being reliable in sensing by saving energy. Our proposed algorithm's target is to schedule the sensor nodes in such a way that they can monitor a region efficiently. We compare our scheme with already existing protocol named as stable election protocol, analyzing the network lifetime for different number of nodes in various areas and also the coverage throughout the lifetime.

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Keyword: Heterogeneous mobile wireless sensor network; advanced nodes; efficient coverage and localization;

1. Introduction

In heterogeneous wireless sensor networks (HWSN), the property of heterogeneity can be of many types. Here,

* Corresponding author. Tel.: +91-532-292-2104.
E-mail address: rajatsingh@iiita.ac.in .

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either some of the nodes may have uneven initial energy levels called Energy heterogeneity or may have the ability to communicate to the farthest node called Link heterogeneity or may have the differences in processing capabilities called Computational heterogeneity [1]. A network can become a heterogeneous one when it performs tasks for prolonged duration, because of which their energy gets depleted. Whether it may be from the initial stage or it can be from prolonged operation, heterogeneity can be a problem or an opportunity to perform challenging tasks. For instance if a node has more memory or processing capability then it's best for data aggregation, if node is equipped with a radio which can communicate farther distances are used for communication over large distances [2]. These tasks must be perfectly coordinated in the network between nodes and as time passes it should be reevaluated to assign new tasks to the nodes in the network to benefit more from this abnormality.

There are so many protocols that utilize different heterogeneity of the network to obtain energy efficiency and to increase the stability and lifetime of the network. So, HWSNs clustering algorithms are classified into two types: those which give more importance to the stability of network, and those to energy efficiency. Most of these algorithms network are reliable, provide better energy efficiency and increase the lifetime of the network. But there will be a trade-off between the quality of service and the life time of the network. If for better performance we use more energy consumption per node, then as a result the lifetime of the network decreases. For instance, stable election protocol (SEP) [3] increases stability period (the time period until first node dies in the network) whereas the Stochastic Energy-Efficient Clustering algorithm [1] concerns more about energy efficiency of the network as it uses sleep wake scheduling scheme. There are also various applications where coverage is an important parameter measured throughout the network lifetime. As the sensor network has limited lifetime, some of nodes may die in a certain regions making a void zone where sensing doesn't takes place. As a solution we can either introduce some new nodes in those regions or move some existing nodes from high density neighboring regions to this void region. Therefore we can use mobility protocols [4,5] to improve the results.

Perhaps, we can get the best result if we introduce heterogeneity which helps increase stability, lifetime, and energy efficiency by taking best aspects of the above protocols. Also by increasing the coverage ratio [6] through mobility that can be a mobile sink or the mobile nodes, the result can be improved. For example, a single node consisting of more energy can cover a region for a longer period than the one which has less energy. So we can move this node to that region which does not have alive node. This process depends on the terrain and the number of nodes in the network.

In this paper, we have considered two different types of nodes which differ in their energy levels. The sink is located at the center of the network and the coordinates of each and every node is known. We also assume that nodes are mobile but the motion is restricted to vertical or horizontal direction only. Using this model, we are proposing a protocol named ECRM (Efficient Coverage Ratio using Mobility) in Heterogeneous WSN. We have used the term efficient coverage ratio because we have taken the ratio of total area covered by the nodes to that of the total network area. This protocol unlike the previous ones is heterogeneous in the sense that the nodes with more energy are subjected to task more often than the other low energy nodes in the network, thus increasing the lifetime of the network. We will show by simulation that the ECRM protocol gives higher throughput and greater lifetime than the clustering protocol for stability. It is also shown that our protocol has good coverage ratio throughout the network lifetime. We will also show that ECRM is energy resilient than any other heterogeneous protocol since we also introduced sleep wake scheduling algorithm and it yields to longer lifetime and coverage.

The rest of the paper is organized as: Section 2 defines our proposed protocol ECRM for HWSN. In Section 3, we discuss various results obtained through simulation. Section 4 concludes the work.

2. Proposed Protocol

2.1. Network Deployment

First we deploy the heterogeneous wireless sensor nodes on a ground layer which is a 2-D rectangular area where 'n' nodes are placed randomly. The nodes consist of a combination of both normal nodes and the advanced nodes where the advanced nodes have energy little bit larger than that of the normal nodes. The division of energy and the ratio of normal nodes to the advanced nodes are as per the Stable Election Protocol [3]. If 'n' is the total number of nodes then the advanced nodes are given as '$m*n$' (m is the fraction of the total number of nodes n). Hence, the total number of normal nodes is given as '(1-m)*n'. Now as for the energy, if we assume the energy of a normal node is 'E_o' then the energy of each advanced node is 'E_o*(1+α)'. This system has practically $\alpha*m$ times more energy and virtually $\alpha*m$ more nodes than normal network. The organization of normal nodes, advanced node and a sink node on the 2-D plane is shown in the Fig 1.

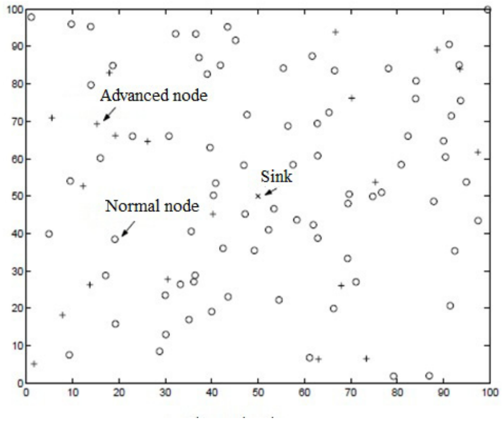

Fig. 1. Deployment of Normal and Advanced nodes

21	22	23	24	25
20	19	18	17	16
11	12	13	14	15
10	9	8	7	6
1	2	3	4	5

Fig. 2. Grid numbering for a 5x5 matrix grid

2.2. Virtual Grid Formation

The next step involves dividing the plane into grids in both row and column wise throughout the entire plane, and each grid size is obtained from the sensing radius of the node. Since the largest distance covered in a grid is the diagonal, and if we take it as 'R_s', then the dimension of each grid will be '$(R_s/\surd 2)\times(R_s/\surd 2)$'. Each grid contains the advanced nodes and the normal nodes in a random order. The total number of grids in the plane is obtained by the ratio of the total area of the plane to that of a single grid, assuming same area for all the grids. Thus the node's location is determined by the grid it belongs to, in the whole network region.

In our approach, the first step involves identifying the overload, neutral and under load state of the corresponding grid. Let us consider that the r^{th} grid have 'L_r' number of nodes. The average number of nodes in each grid is given by 'A' which is the ratio of number of nodes, deployed initially to the number of grids. Then we can calculate the load using the following conditions:

a. *if $L_r > A$ then r^{th} grid is in overload state,*
b. *if $L_r = A$ then r^{th} grid is in neutral state,*
c. *if $L_r < A$ then r^{th} grid is in underload state.*

After calculating the load of the grid in the sensor field, we find out the move of the sensor node. Only the overloaded grid sensor nodes draw in left or right direction. At first we will scan all of the grids sequentially i.e., starting from 1st grid to last, to determine their current load status. An under load grid will have nodes shifted into it from an adjacent overload grid, in an order starting from the 1st grid to the last grid. In such a way, we distribute the nodes from high density regions to low density regions. The r^{th} grid can take node from grids which are above, below, left or right of that grid. An example of a 5x5 virtual grid formation with their grid numbering is shown in the Fig 2. Here, we can say that if the 9th grid is in underload state, then it can take in the mobile node only from any of the 2, 8, 10 or 12th grid, if possible, but never from 1, 3, 11 or 13th grid.

2.3. Energy and Coverage Efficiency Solution

The energy dissolution is calculated by the formula of radio energy model as per the SEP protocol [3] for both the transmission and receiving the signal from the node as per the distance between the two nodes. In each round, one node in each grid will sense and transmit the data to the sink. This selection of node in every grid is determined based on their energy values.

At first energy of each and every node is measured, the node having the highest energy in the every grid is kept awake to sense the region of the grid, and the remaining nodes are kept in sleep state. In every round, we calculate the energy of each of the nodes to find the highest energy node, so that it can be kept in the wake state to sense the grid. We design the sleep wake scheduling scheme [7] in such a manner that in every grid, one sensor node will be active, and rest of other will be in doze state. Hence the energy is saved to improve the lifetime of the network. The sleep-awake applied in a network is shown in the Fig 3.

We check the grid in every round, after sensing and transmission, for alive nodes. If the grid is empty i.e., if all the nodes in the grid die, then it search the neighboring grid for the extra node. One node from that grid, which has the maximum number of extra nodes, is shifted to this grid to cover the void region. Thus this scheme provides efficient coverage as long as there are minimum numbers of nodes that can cover the grid.

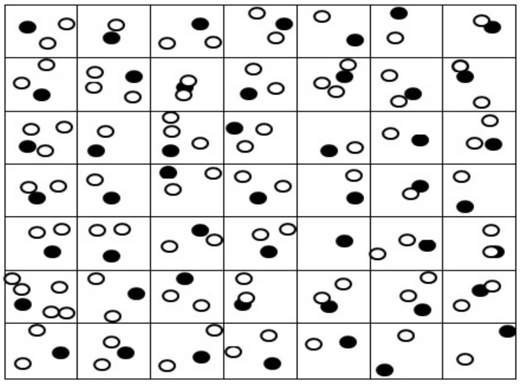

Fig. 3. Sleep wake scheduling applied

3. Results and Analysis

In this section, the results of our protocol are shown. To ensure that maximum area is covered for longer time is the main objective of our protocol. We use MATLAB 7.10.0 to simulate the Efficient Coverage and Localization scheme performance. In our analysis, we presume that the sensor nodes have mobility features. In mobility, the energy is lost only due to sensing and communication operation performed by sensor node, but not due to mobility because we have assumed that the sensor is self-movable without energy loss through the battery. Initially, all the sensor nodes are in active state, and after checking the energy level and distance among the nodes, they can be assigned into sleep state. Using the below table assumptions we deploy the network, give energies to each node, sink is placed at the centre of the plane, and it is not mobile. The energy of advanced node will be 3 times more than normal nodes. The other simulation parameters are given in Table 1.

Initially we divide the region into subareas which is virtually created. These individual subs areas are said to be grids which have area as explained in section 2. Nodes which are deployed in the plane are allocated to each grid as

Table 1. Simulation Parameters

Simulation Parameters	Values
Network field 2-D size (area)	40m x 50m, 40m x 40m, 50m x 60m,
Number of sensor nodes (N)	100, 80, 150
Number of advanced nodes (a_n)	20% of N
Number of normal nodes(n_n)	N - (20% of N)
Energy of an advanced node (Eo)	4J
Energy of a normal node	1J

Location of the sink node	Centre
Sensor network deployment type	Random
Simulator software Version	MATLAB 7.10.0

per the virtual grid numbering given in the above Fig 2. The number of grids and the randomly deployed nodes are shown in the Fig 4. We observe that the grids with less number of nodes namely 1, 3, 8, 11 and 19 are said to be in under load state, whereas the grids 2, 7, 15, 20 are in overload state.

Initial random spreading of nodes in sensor field is in unbalanced state. To balance the sub area, each grid has to perform scan procedure. Now since, we know the average number of nodes to be there in each grid, hence the advanced nodes in the grid will be moved first. After the advanced nodes are balanced, the total number of nodes (both advanced and the normal nodes) are scanned again to obtain the approximately equally distributed nodes in the grid as shown in the Fig 5.

After this relocation of sensor node, the grids 1, 3, 8 and 19 have now the sufficient number of nodes. Now we calculate the energy dissipation for forwarding the packet to the sink node. After calculating the energy of each sensor node, we schedule the sleep wake scheduling according to the distance and the energy level. We put that sensor node into awake state which senses the same event, and its energy level is greater than the other nodes of that grid, and put the remaining, if any, in sleep state.

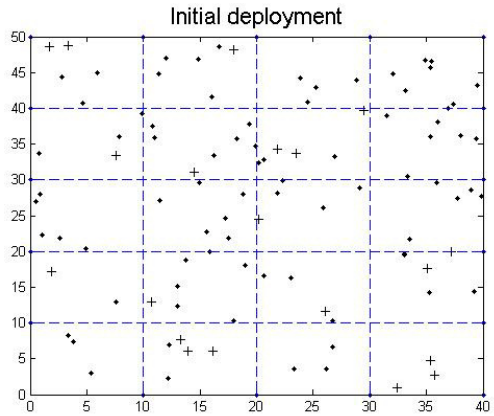

Fig. 4. Plane divided into grids: • -normal +-advanced

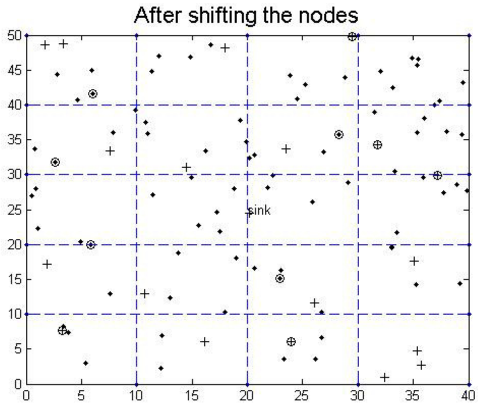

Fig. 5. After the nodes are shifted

3.1. Lifetime of ECRM Network

We assume that a node is dead when its energy is less than the threshold level i.e., 0.3J in this case. The energy losses would be happened by transmitter, receiver and Data aggregation. The total number of rounds the network operates is until the last node in the network dies. We compare the lifetime of the network with that of SEP heterogeneous protocol which focuses mainly on the stability of the network. Because of the sleep wake applied, the advanced node is helpful in this method to increase the lifetime of the network since it has extra energy. The following Fig 6 is the plot between number of alive nodes and the number of rounds, for $m = 0.2$ and $\alpha = 3$. This figure shows that our protocol can work for more number of rounds. SEP works for 2000 rounds whereas ECRM works for 3500 rounds which is about 70% greater i.e., the lifetime of the network is greater for ECRM than SEP. We found that the performance will increase when m and α value is increased.

3.2. Coverage of the Network

We study the coverage of network depending on the grid's sensing. A grid is said to be covered if it has at least one node that can sense that region. With the shift of nodes from the neighboring grid, we can ensure that a grid is covered for a period until no adjacent grids have alive nodes to shift. The ratio of number of filled-grids (having alive nodes for sensing) to the total number of grids is considered as the percentage covered area. We have applied the above grid based coverage formula on both: SEP and ECRM, in order to compare the coverage ratio, and also to check that up to what number of rounds it would cover the field. Fig 7 shows that there is a drastic fall in the coverage of network in SEP, where as in ECRM there is a step by step drop at 1200, 1400 and 2000 rounds of about 10%, 5% and 10% respectively. We can also see that the remaining 10% coverage point arrives very early in case of SEP i.e., at 1250 rounds, whereas in case of ECRM, it arrives at 2700 rounds. Hence, we can say that at this point only the grids having more advanced nodes are covered in the network.

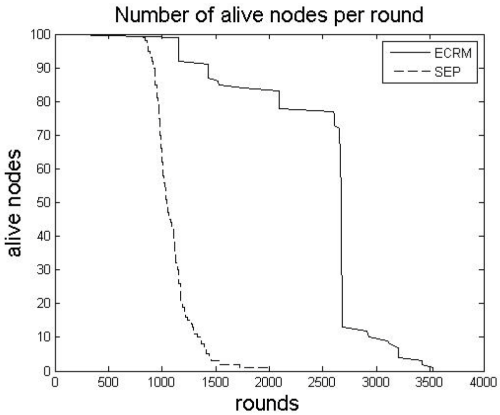

Fig. 6. Number of alive nodes when 100 nodes in 40m x 50m

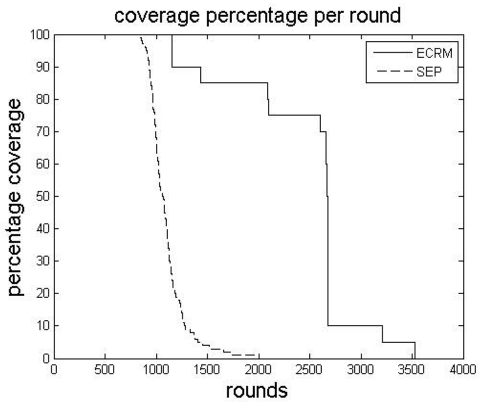

Fig. 7. Coverage percentage when 100 nodes in 40m x 50m

3.3. Sensitivity of ECRM

The sensitivity is obtained in terms of the stability period i.e., when the first node dies in the network. Among all the heterogeneous protocols proposed till now, SEP is having the highest stability period. This stability period depends on the area of the network as well as on the number of nodes deployed in it. In case-1 (Fig 8), we have considered 80 nodes deployed in 40m x 40m field area. We observed that at the "knee point" in SEP, there are about 3 dead nodes in ECRM. In case-2, (Fig 9), we have considered 150 nodes deployed in 50m x 60m field area. Here, we found that there is only 1 dead node in case of ECRM at the "knee point" of SEP. This is because there are more nodes to cover smaller region. This happens when the number of nodes is greater than what is required in an area, and hence the stability region of ECRM increases. There will not be much drop in the network coverage since even a node die another node takes its place to cover that region as shown in Fig 10 and Fig 11.

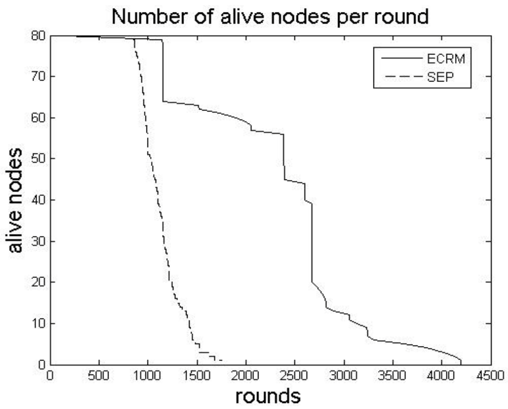

Fig. 8. Number of alive nodes when 80 nodes in 40m x 40m

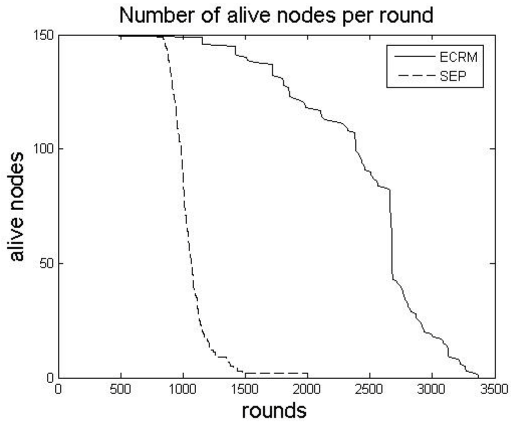

Fig. 9. Number of alive nodes when 150 nodes in 50m x 60m

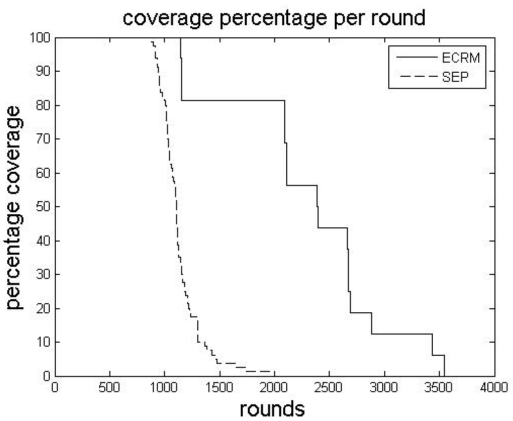

Fig. 10. Coverage percentage when 80 nodes in 40m x 40m

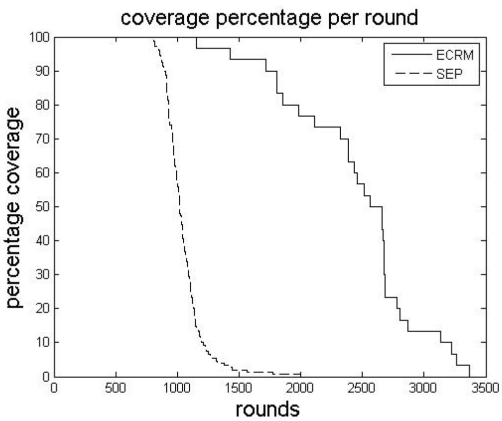

Fig. 11. Coverage percentage when 150 nodes in 50m x 60m

4. Conclusions

We have proposed the ECRM protocol such that it elects the sensing node depending on the energy of the nodes, and provide more coverage in high lifetime using the concept of mobility of sensor nodes. The simulation results show that it has better lifetime and coverage than SEP under same conditions. ECRM protocol is highly scalable as if the additional nodes are added, then they can be shifted evenly. But if the terrain is uneven, or an extra region is added after the step of shifting of nodes, it will be difficult to organize the network, and to maintain high coverage ratio. Unlike [8], the movement of nodes is limited to its adjacent grid, and there is no such grid that has both an incoming and an outgoing node. Furthermore, our ECRM protocol can be applied to any sized networks as long as it has sufficient number of nodes necessary to cover the network.

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