Energy and Coverage Efficient Static Node Deployment Model for Wireless Sensor Network

Ragib Shakil Rafi, Md. Mizanur Rahman, Nishat Sultana, Mahmud Hossain

Abstract- WSNs are energy constrained, and recent works are being carried out by many engineers and scientists to make the WSNs more energy efficient. Primarily, WSNs can be categorized into two types: random and deterministic. We have concentrated our research interest to design an energy efficient deterministic WSN. In this paper, a Seven Node Hexagonal Deployment (SNHD) scheme is proposed i.e. hexagonal deployment with an additional node at the centre of every hexagon. It has been proved by mathematical analysis and MATLAB simulation that our proposed model is more energy efficient and have higher lifetime compared to Tri-Hexagon-Tiling (THT), Square grid, and LEACH random node deployment. Moreover, by mathematical analysis it has also been shown that SNHD deployment scheme requires less number of nodes to cover any region compared to other methods.

Index Terms- Coverage, Energy Efficient, Hexagonal Deployment, LEACH, Network Lifetime, Node Deployment, WSN.

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1 INTRODUCTION

Wireless sensor network (WSN) is a large scale integrated network, composed of low-power, low-cost multifunctional small sensors which are capable of data sensing, processing, and communicating through radio channel with each other. As WSNs are energy constrained networks [1], one elementary way of reducing energy consumption and enhancing lifetime is sensible deployment of sensor nodes within the network area. The deployment of nodes is either static or dynamic depending on their structure and the way of routing. In static or deterministic deployment method, positions of sensor nodes are fixed and they use predefined paths to route their data to the base station (BS). In dynamic routing nodes are moveable throughout the deployed field and routing paths are updated continuously to route data to the sink or BS. In this paper, we emphasize on deterministic node deployment method and propose a deterministic node deployment model, Seven Node Hexagonal Deployment (SNHD). We compared our proposed model to one random Low Energy Adaptive Clustering Hierarchy (LEACH) [2] and two deterministic node deployments: square grid, Tri-Hexagon Tiling (THT) [3] on the basis of coverage and energy consumption.

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Coverage analysis is based on how efficiently a field can be covered with minimum number of nodes and energy consumption analysis was done to reduce network energy consumption by optimizing the transmitting distance, sequentially changing heads, and applying data aggregation technique.

The reminder of our paper is structured as follows: section 2 is relevant previous works on node deployment and energy aware routing schemes are outlined. Section 3 explains different existing node deployment strategies. In section 4, proposed node deployment model and calculation of the coverage and energy consumption are discussed. In section 5, results and discussions are presented. Finally, conclusion is drawn in section 6 with vision to further improve this work.

2 PREVIOUS RELATED WORKS

Major objective of any node deployment technique is to provide full coverage to a certain region with minimum number of nodes. So, cost and deployment quality is the two factors that come first while considering any deployment technique [4].

Depending on the types of deployed nodes, a WSN can be either homogenous or heterogeneous. In a homogenous sensor network, each node has same energy level, sensing range, and processing capabilities. On the other hand, in heterogeneous sensor network, nodes have different sensing range, energy level, and processing capabilities. Heterogeneous sensor network is complex in nature and more sophisticated protocols with better network manageability are needed to handle this. Recent researches are running on mixing the homogenous and heterogeneous network together to improve

the network life-time [5]. Our analyses are based on homogenous network.

Grid deployment method is a part of deterministic deployment scheme of sensor nodes and geometric-shapes like square, hexagon, equilateral triangle are used in grid deployment. In [3], a comparative study is done on two grid deployment methods: Tri-Hexagon-Tiling (THT) and square grid while THT has been suggested as a good deployment method.

It was found in [6] that, to ensure the continuous coverage and connectivity in WSN, sink-hole routing must be avoided. Phenomenon of dying the nodes nearest to the sink is addressed as 'sink-hole routing'. To fulfill this desired coverage and connectivity, power aware non-uniform deployment was suggested.

Comparison between multihop and single hop scheme is an everlasting topic in WSN. Sensor network with multihop communication has been preferred in [7], [8] while in [9], [10] single hop communication over multi-hop has been preferred considering practical amplifier characteristics and high end to end data transferring probability. But in [2] multihop routing has been shown to be better in efficient use of energy.

Clustering is a means of saving energy and designing a high lifetime network. Cluster can be done in many ways but it depends on the deployment methods of the nodes and on expected routing scheme. As was shown in [11], nodes were clustered in a big hexagon and comparative study on three different data transmitting schemes: direct reporting, reporting via cluster head (CH) situated at the center of the hexagon, and reporting via random CH are explained. Hex-MASCLE algorithm has been proposed in [12] to cluster the deployed nodes and to improve WSNs' lifetime.

Rotation of CHs to optimize the use of stored energy of each node would be a great solution to combat energy consumption issue. To achieve this CH rotation method proposed in LEACH [2] has been used to cluster the nodes in the proposed deployment method.

3 NODE DEPLOYMENT METHODS

3.1 Random

In the random deployment, the nodes are randomly scattered with respect to the radial and angular directions from the BS as shown in the fig. 1(a) Sensors in the field have equal probability of being positioned independently of the other sensors. Though the, sensor nodes are homogenous, they have some equal parameters like energy, bandwidth etc., but uneven distance among them creates problem. This introduces data latency and uneven energy dissipation throughout the network.

3.2 Square Grid

In this deployment scheme, total field is covered with regular square shaped cells as shown in fig. 1(b) If any circular field of radius R_F is covered with X number of cells, X is approximated to, $(\sqrt{n} -1)^2$ [3], where n is the total number of sensors. So, the sensing equation of each node can be written

as,

$$R_{Sense} = \sqrt{\frac{\pi R_F^2}{n}}$$ (1)

Where R_F is the field radius [3]. Here, Sensing radius of a node is equal to the edge length of the square cell. In this scheme, to cover an area of, 4 nodes in a cell exactly cover $4 \times (1/4) \times (\pi D^2)$ areas. So, redundant area covered by 4 nodes is:

$$(\pi - 1)D^2 = (\pi - 1)R_{sense}^2$$ (2)

Therefore, a single node covers $0.54 D^2$ redundant areas, where D is the edge length of any square cell.

3.3 Tri-Hexagon Tiling

Tri-hexagon-tiling (THT) is formed by using a hexagon and six equilateral triangles with each edge of the hexagon. This pattern can be drawn by placing a hexagon as the center and other six hexagons placed at each corner of the center hexagon and as shown in fig. 1(c) Sensors are placed at every grid point. In THT, sensing radius of each node is equal to the edge length of hexagon and it can be expressed as:

$$R_{sense} = \sqrt{\frac{4\pi R_F^2}{3\sqrt{3}\,n}}$$ (3)

Where R_F is the field radius [3]. Here, Sensing radius of a node is equal to the edge length of the square cell. In this scheme, to cover an area of, 4 nodes in a cell exactly cover $6 \times 1/3 \times \pi D^2$. So, redundant area covered by 6 nodes $3.69 D^2$. Therefore, a single node covers $0.615 D^2$ redundant areas, where D is the edge length of any hexagon.
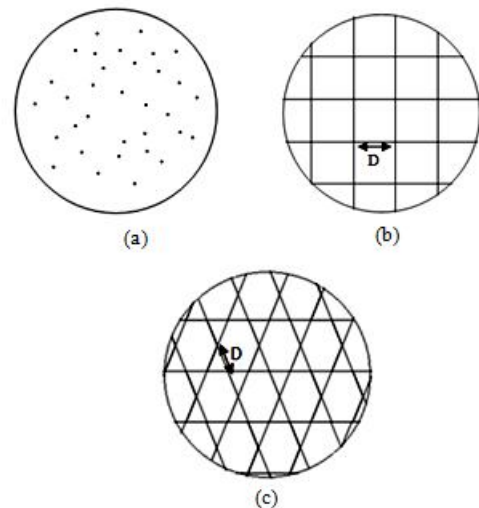

Fig.1. Node deployment techniques. (a) Random, (b) Square grid, (c) THT

4 PROPOSED SEVEN NODE HEXAGONAL DEPLOYMENT (SNHD)

Fig. 2 shows the SNHD deployment method. In this proposed scheme, seven regular hexagons form the basic structure by placing one at the center and six others are placed with each edge of the center hexagon. Nodes are placed at each cross section and an additional node is placed at the center of every hexagon.
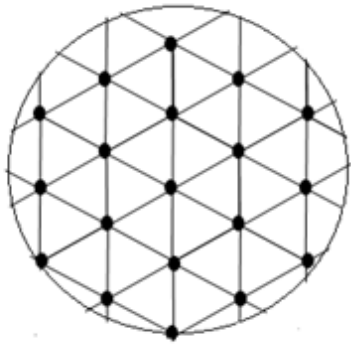
Fig.2. SNHD deployment

So, every hexagon consists of seven nodes. This additional node is placed to reduce the redundant coverage that exists at other deterministic node deployment method discussed in this paper. For SNHD, relation of sensing radius of a sensor node and edge length of the hexagon is,

$$D = \sqrt{3}\, R_{sense}{}^2 \qquad (4)$$

The relation between field radius and sensing radius of a node is:

$$n = 3 + \sqrt{\frac{8\pi R_F{}^2}{9\sqrt{3}\, R_{sense}{}^2}} \qquad (5)$$

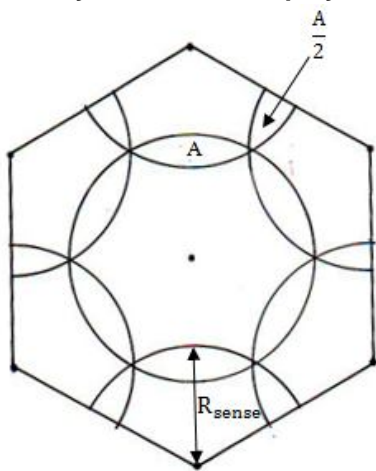## 4.1 Coverage Analysis of SNHD Deployment

Fig.3. SNHD sensing coverage strategy

Area of one hexagon cell = $(3\sqrt{3}\ D^2)/2$. To cover this area in SNHD method, we used 7 nodes. Coverage area of centre node is πD^2. For other six nodes which are at each corner, only one third of their coverage area is taken into account for one cell.

So, redundant coverage for one cell is $0.5435\, D^2$ and this redundant area is covered by 6 nodes. Each node covers extra $0.09D^2 = 0.27R_{sense}{}^2$. Fig. 3 shows the deployment method used for redundant coverage calculation for one cell in SNHD deployment. Redundant coverage is a concerning issue as for sensing large area nodes use more sensing power to cover the

redundant area. On the other hand, multiple sensing of an area creates data loads for the CHs as heads have to receive and aggregate same data for multiple times.

4.2 Cluster Formation Method of SNHD Deployment

As described earlier, seven hexagons construct a single cluster in the proposed SNHD deployment method. Each hexagonal cell carries seven sensor nodes. The sensor nodes positions can be decided either by GPS or the signaling within themselves and the BS and testing the signal strength or test message energy strength. Centre node of the centre hexagon of any cluster will be the initial CH. For the cluster formation, initial CHs will broadcast cluster formation message to the nodes. Nodes that are situated within 2×D distance of any initial CH, where D is the edge length of any hexagonal cell, will be included in the cluster under that initial head. At 2×D distance, each initial CH will find 6 nodes those are overlapped with another cluster but distance of these nodes from the initial CH of that overlapping cluster will be greater than 2×D. So, the overlapped nodes those lie within 2×D distance from initial CH of any cluster, will be included in that cluster. Other overlapped nodes beyond 2×D distance, receive cluster formation messages from different CHs and will decide which CH has minimum distance from it. If it finds two CHs at a same distance, then it will take decision based on the distance of the CH from the BS and will consider itself on the cluster of the head which has less distance than another one. Moreover, if some nodes, which CHs are at same distance from the base and are found to be on the boundary of two clusters then they will be distributed among the clusters alternately. This method will be followed throughout the deployed network.

4.3 Cluster Head Changing Method of SNHD Deployment

Here, in the proposed SNHD method, heads of clusters will be changed synchronously throughout the network.
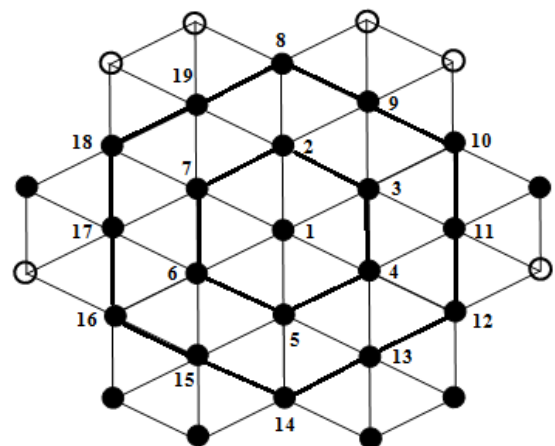

Fig.4. Cluster head changing method of SNHD

Fig. 4 explains the changing method of CHs in SNHD. Suppose clusters are formed as described according to the cluster formation method described in section 4.1. In fig. 4, black nodes are in the same cluster. White marked nodes are

into different clusters. In fig. 4, two black color hexagons (an inner and an outer) are drawn using the clustered nodes. Nodes that are situated at the perimeter of these two hexagons are selected as clustered heads. To synchronously choose the heads, nodes are numbered maintaining a synchronism, following the clockwise or counter clockwise rotation. In this example clockwise rotation has been chosen. Every cluster in the network will follow this procedure. So, when node 1 is head in one cluster, node 1 will be the head in other clusters. Number of CHs can be increased further taking the nodes that are in the same cluster but not included in two big hexagons drawn at fig. 4

4.4 Data Communication Process of SNHD

SNHD follows multihop communication scheme. Sensor nodes will send their data to the CHs through the TDMA slots allocated by the CHs and CHs will communicate with each other by CDMA technique. The clusters will be allocated CDMA codes by the BS. Every head of a certain cluster should use the CDMA code allocated for its cluster. This communication process is explained with the following fig. 5. In fig. 5, there are three CHs and every head has three nodes. In the first step, every sensor node will sense the data and in the second step nodes will send the data to the CH. This 2nd step will be split into 3 time slots and one slot will be allocated to each node to ensure that when one sensor node is sending data others are not sending to avoid collision. Because if collision detection protocol is used and collision occurs, then the corresponding data will be required to be sent for the second time or more times which will cause more loss of energy. At the third step, each CH will aggregate the received data. During 4th step, 1st CH (nearest to the BS) will send the data to the BS. At 5th step, data of 2nd CH will be sent to the 1st CH. 6th step will be used by the 1st CH to send the received data of 2nd CH to the BS.
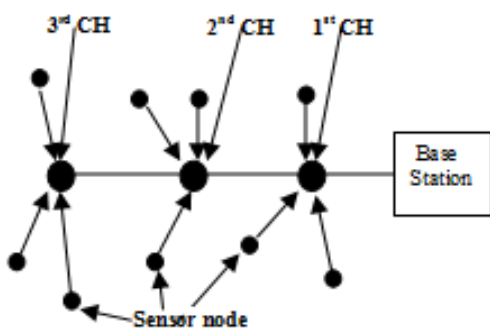

Fig.5. Data communication process of SNHD

At the same time 3rd CH will send its data which will be received by the 2nd CH. At 7th step data of 3rd CH will reach to the 1st CH and during 8th step it will be transmitted to the BS by the 1st CH. The steps are shown in fig. 6.
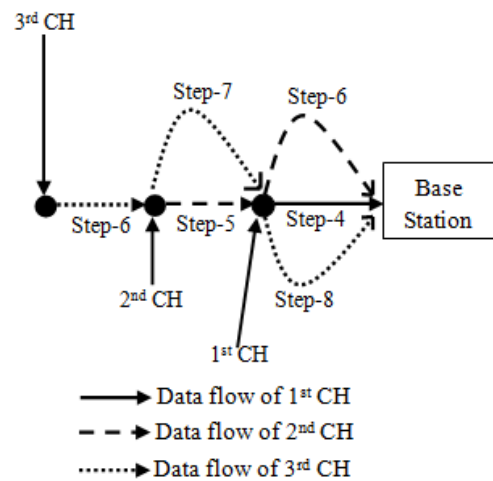

Fig.6. Data transmission cycle using 3-hops /heads in SNHD method. (CH= Cluster Head, without data sensing, receiving, and aggregating steps)

4.5 Energy Consumption of SNHD

Energy consumption is a critical issue of WSN as less energy consumption increases the network lifetime, while more consumption decreases the lifetime. Basically sensor nodes loss their energy in three ways in wireless sensor network: in data sensing, processing, and transmitting that data. Direct transmission of data to the BS wastes more energy [3], [8]. Thus by forming clusters and communication through CH is preferred by the researchers and many other techniques are being applied such as data aggregation, rotation of CHs to enhance network lifetime. In SNHD model, we consider multihop communication through CHs and the CHs are being rotated synchronously within every cluster throughout the network as discussed in section 4.3.

The reason behind CH changing is to optimize the energy utilization of every node in the cluster. Data aggregation proposed in LEACH is considered in our model also [5]. So, total energy consumed by a CH in our model is:

$$E = E_r + E_a + E_t \tag{6}$$

Where, E_r = receiving energy, E_a = data aggregation energy, and E_t = transmitting energy. E_t is calculated following the equation of first order radio model.

5 RESULT AND DISCUSSION

We analyzed the relation between sensing radius of a node and its redundant area covered by every node. Fig.7 is plotted using the simulation values and it shows that for a given sensing radius, a node in SNHD deployment covers less redundant area than other two methods. So, for a given sensing radius, our scheme performs better by covering greater areas with less overlapping regions than square grid and THT. Minimum overlapping regions ensures generation of minimum number of similar data and less sensing energy.

Processing of similar data sent by different nodes will certainly waste more energy of CHs. Thus by reducing overlapping regions and processing minimum number of similar data, energy consumption is reduced at every CH in the proposed node deployment method.
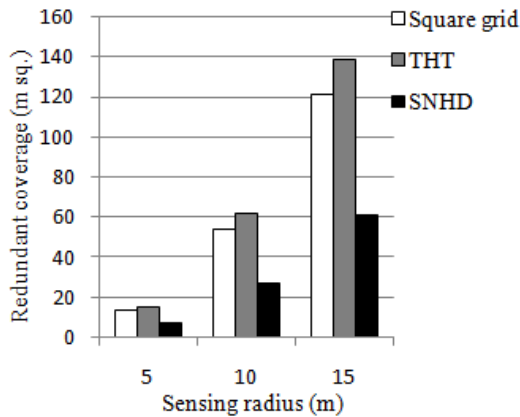

Fig.7. Per node redundant area covered if every node is considered to have equal radius and the sensing radius to edge length ratios are kept unchanged of different deployment techniques
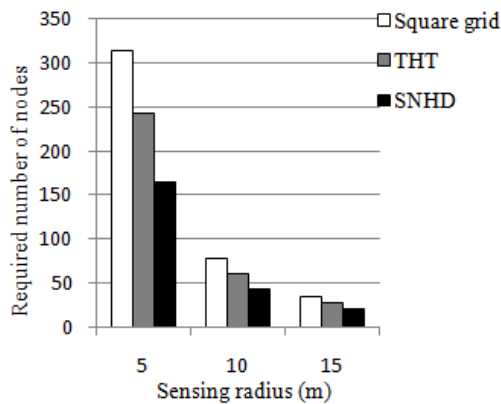

Fig.8. Number of nodes required to cover a circular area of 50m radius for Square Grid, THT and SNHD deployment.

Fig. 8 shows the number of nodes required to cover a certain region for a given sensing radius. We have plotted fig. 8 for different values of sensing radius to cover a circular field of 50m radius. Among the discussed deployment methods, SNHD requires less number of nodes. This is because, in SNHD method, nodes cover less redundant area if equal sensing radius is considered for all deployment techniques. Applying equal sensing radius for a single node and minimum overlapping condition, hexagonal cells in SNHD method cover more area than other methods. Therefore less number of nodes is required in SNHD to cover a given area. So, to cover a given field with less number of nodes compared to other methods proves our method to be more cost effective. Fig.9(a) shows our node deployment technique. 110 nodes are deployed on a 95m×86.6m field. In the figure a single hexagon cell is marked. Fig. 9(b) and fig. 9(c) show the number of alive
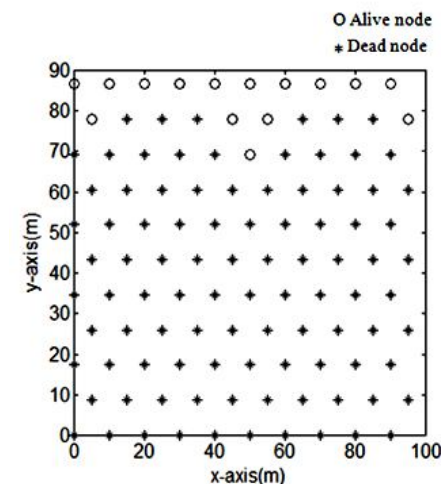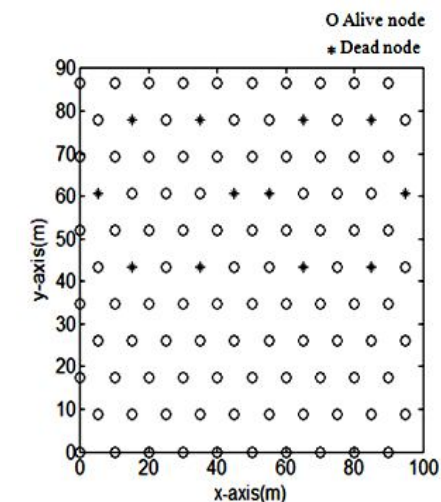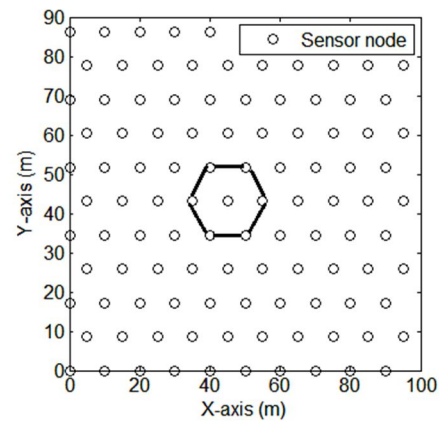
and dead nodes after 1400 and 2000 data transmitting rounds.

Fig.9.Node deployment in SNHD model. (a) 110 nodes are deployed on a 95m×86.6m field. In the figure a single hexagon cell is indicated. (b) Position of dead and alive nodes after 1400 rounds. (c) Position of dead and alive nodes after 2000 rounds.

Fig.10 shows the network lifetime comparison of our deployment technique with others. From fig.10. It is evident that SNHD node

deployment method ensures greater network lifetime than any other deployment technique as discussed in this paper. It's always an important issue to make all the nodes in a WSN to work together for more number of data transmission rounds as the network will be fully covered for that period of time. According to the fig.10, SNHD method provides full coverage for longer time than other methods. It's a prime need to sustain full coverage for a long time. Otherwise, sensed data from the total field will not be collected efficiently and result of monitoring the overall field will be less efficient.

Fig.10. Comparison of Network lifetime of LEACH, SNHD, Square Grid and THT deployment techniques.

6 CONCLUSION

Based on the analytical and simulation results, it is proved that, a given area is covered in an energy efficient way with less number of nodes in the SNHD deployment model. In this scheme the nodes are actually placed at equal distances from neighbor nodes, transmission energy is optimized. Moreover, data aggregation and synchronous rotation of the CHs helps in better utilization of the valuable network power.

In this work processing energy consumption was not considered for simplification of the analysis. Delay was not also calculated for the proposed model. In near future, a more detailed WSN model considering processing energy, delay and active-sleep modes of the nodes will be analyzed. Moreover, we also hope to implement and observe the performance of our proposed SNHD WSN deployment model.

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