Proficient D-HEED Protocol for Maximizing the Lifetime of WSN and Comparative Performance Investigations with Various Deployment Strategies

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Abstract

In this paper, work has been extended to prolong the lifetime and energy proficiency of wireless sensor network. An idea of deterministic HEED has been proposed that take care of cluster head which has not been elected in $1/p_i$ rounds. Here the comparative investigations have been reported to ascertain the performance of HEED, Multilevel Heterogeneous-Hybrid Energy Efficient Distributed Protocol (MH-HEED) and the Deterministic-HEED (D-HEED) for Wireless Sensor Network (WSN) in case of different deployment strategies. The results envisage that there is increase of about 364.3%, 268.7% & 300% comparing D-HEED over H-HEED, whereas this increase is about 25%, 22.9% &15.38% over MH-HEED in case of circular, grid and rectangular deployment strategies respectively.

Keywords: *Wireless Sensor Network, Network Lifetime, Heterogeneity, HEED Protocol*

1. Introduction

A wireless sensor network (WSN) can be defined as a network consists of low-size and low-complex devices called as sensor nodes that can sense the environment and gather the information from the monitoring field and communicate through wireless links; the data collected is forwarded, via multiple hops relaying to a sink (also called as controller or monitor) that can use it locally, or is connected to other networks [1]. A sensor node usually consists of four sub-systems [2] i.e. sensing unit, processing unit, communication unit and power supply unit.

In WSN, the sensor nodes are deployed in a sensor field. The deployment of the sensor nodes can be random (i.e. dropped from the aircraft), regular (i.e. well planned or fixed) or mobile sensor nodes can be used. Sensor nodes coordinate among themselves to produce high-quality information about the physical environment. Each sensor nodes collect the data and route the data to the base station. All of the nodes are not necessarily communicating at any particular time and nodes can only communicate with a few nearby nodes. The network has a routing protocol to control the routing of data messages between nodes. The routing protocol also attempts to get messages to the base station in an energy-efficient manner.

The base station is a master node. Data sensed by the network is routed back to a base station. The base station is a larger computer, where data from the sensor network will be compiled and processed. The base station may communicate with the Remote Controller node via Internet or Satellite [2, 3]. Human operators controlling the sensor network send commands and receive responses through the base station.

HEED (Hybrid Energy Efficient Distributed) protocol [4] is the clustering protocol. It uses residual energy as primary parameter and network topology features (e.g. node degree, distances to neighbours) are only used as secondary parameters to break tie between candidate cluster heads, as a metric for cluster selection to achieve load balancing. Here all the nodes are assumed to be homogenous i.e. all sensor nodes are equipped with same initial energy. But, in this paper we study the impact of heterogeneity in terms of node energy. We assume that a percentage of the node population is equipped with more energy than the rest of the nodes in the same network and this is the case of heterogeneous sensor networks. As the lifetime of sensor networks is limited so, there is a need to re-energize the sensor network by adding more nodes. These nodes will be equipped with more energy than the nodes that are already in use, which creates heterogeneity in terms of node energy, leads to the introduction of H-HEED protocol.

In this paper, we have proposed the new approach to the HEED protocol by the introducing heterogeneity in the network (i.e. sensor nodes are equipped with different initial energy) called Multi-level Heterogeneous- HEED (MH-HEED) and Deterministic-HEED (D-HEED) on the different node deployment models. Finally, we have evaluated and compare the performance of Homogeneous-HEED (H-HEED), MH-HEED and D-HEED protocols.

The remainder of the paper is organized as follows. In Section 2, we briefly review related work. Section 3 describes the clusters formation in the HEED protocol. Section 4 describes network assumption model and section 5 shows the node deployment strategies in case of H-, MH- and D-HEED. In section 6 the results has been discussed. Finally, Section 7 gives concluding remarks.

2. Related Work

W. R. Heinzelman, A. P. Chandrakasan and H. Balakrishnan [5] proposed Low Energy Adaptive Clustering Hierarchy (LEACH) protocol in 2000. It is one of the most popular hierarchical routing algorithms for sensor networks. The idea is to form clusters of the sensor nodes based on the received strength of the signal and use local cluster heads as routers to the sink. This will save energy since the transmissions will only be done by such cluster heads rather than all sensor nodes. Optimal number of cluster heads is estimated to be 5% of the total number of nodes. All the data processing such as data fusion and aggregation are local to the cluster. Cluster heads change randomly over time in order to balance the energy dissipation of nodes. This decision is made by the node choosing a random number between 0 and 1. The node becomes a cluster head for the current round if the number is less than the following threshold:

$$T(n) = \begin{cases} \frac{p}{1-p*(r \bmod 1/p)} & if\ n \in G \\ 0 & otherwise \end{cases} \quad \ldots(1)$$

Where p is the desired percentage of cluster heads (e.g. 0.05), r is the current round and G is the set of nodes that have not been cluster heads in the last 1/p rounds. However the limitations of Leach protocol are that it uses single-hop routing within cluster and thus not applicable to networks deployed in large regions, dynamic clustering brings extra overhead, assumes all nodes can transmit with enough power to reach BS, if necessary (e.g., elected as CHs), Each node should support both TDMA & CDMA, failure of cluster head is a problem and cluster head selection is a difficult problem to optimize.

S. Lindsey and C. Raghavendra [6] introduced Power Efficient Gathering in Sensor Information Systems (PEGASIS) protocol in 2002. It is an improved version of LEACH protocol. Instead of forming clusters, it is based on forming chains of sensor nodes. One node is responsible for routing the aggregated data to the sink. Each node aggregates the collected data with its own data and then passes the aggregated data to the next ring.

The difference from LEACH is to employ multi hop transmission and selecting only one node to transmit the data to the sink or base station. Since the overhead caused by dynamic cluster formation is eliminated, multi hop transmission and data aggregation is employed, PEGASIS outperforms the LEACH. However excessive delay is introduced for distant nodes, especially for large networks, where single leader can be a bottleneck.

In 2001, A. Manjeshwar and D. P. Agarwal [7] proposed Threshold sensitive Energy Efficient sensor Network Protocol (TEEN) protocol. Closer nodes form clusters, with cluster heads to transmit the collected data to one upper layer. Forming the clusters, cluster heads broadcast two threshold values. First one is hard threshold; it is minimum possible value of an attribute to trigger a sensor node. Hard threshold allow the nodes to transmit the event, if the event occurs in the range of interest. Therefore a significant reduction of the transmission delay occurs. Unless a change of minimum soft threshold occurs, the nodes don't send a new packet of data. Employing soft threshold prevents from the redundant data transmission. Since the protocol is to be responsive to the sudden changes in the sensed attribute, it is suitable for time-critical applications.

A. Manjeshwar and D. P. Agarwal [8] proposed Adaptive Threshold sensitive Energy Efficient sensor Network Protocol (APTEEN) protocol in 2002. The protocol is an extension of TEEN aiming to capture both time-critical events and periodic data collections. The network architecture is same as TEEN. After forming clusters the cluster heads broadcast attributes, the threshold values along with the transmission schedule to all nodes. According to energy dissipation and network lifetime, TEEN gives better performance than LEACH and APTEEN, because of the decreased number of transmissions. The main drawbacks of TEEN and APTEEN are overhead and complexity of forming clusters in multiple levels, implementing threshold-based functions and dealing with attribute based naming of queries.

In 2004, G. Smaragdakis, I. Matta and A. Bestavros [9] proposed Stable Election Protocol (SEP) protocol. This protocol is an extension of LEACH protocol. It is a heterogeneous aware protocol, based on weighted election probabilities of each node to become cluster head according to their respective energy. This approach ensures that the cluster head election is randomly selected and distribution is based upon the fraction of energy of each node, which assures a uniform use of the energy. In this protocol, two types of nodes (two tier in-clustering) and two level hierarchies were considered.

In 2005, M. Ye, C. Li, G. Chen and J. Wu [10] proposed Energy Efficient Clustering Scheme (EECS) protocol. It is novel clustering scheme for periodical data gathering applications for wireless sensor networks. It elects cluster heads with more residual energy through local radio communication. In the cluster head election phase, a constant number of candidate nodes are elected and compete for cluster heads according to the node residual energy. The competition process is localized without iteration. Further in the cluster formation phase, a novel approach is introduced to balance the load among all cluster heads. But on the other hand, it increases the requirement of global knowledge about the distances between the cluster-heads and the base station.

In 2006, Q. Li, Z. Qingxin and W. Mingwen [11] proposed Distributed Energy Efficient Clustering Protocol (DEEC) protocol. This protocol is a cluster based scheme for multi level and two level energy heterogeneous wireless sensor networks. In this scheme, the cluster heads are selected using the probability based on the ratio between residual energy of each node and the average energy of the network. The epochs of being cluster-heads for nodes are different according to their initial and residual energy. The nodes with high initial and residual energy have more chances to become the cluster heads as compared to nodes having low energy.

O. Younis and S. Fahmy proposed [4] Hybrid Energy Efficient Distributed clustering Protocol (HEED) protocol in 2004. It extends the basic scheme of LEACH by using residual energy as primary parameter and network topology features (e.g. node degree, distances to neighbors) are only used as secondary parameters to break tie between candidates and cluster heads

The HEED clustering protocol [4] uses a hybrid criterion for cluster head selection, which considers the residual energy of each node and a secondary parameter, such as the node's proximity to its neighbors or the number of its neighbors. The clustering process is divided into a number of iterations and in each iteration, nodes which are not covered by any cluster head have double their probability of becoming a cluster head. Since these energy-efficient clustering protocols enable every node to independently and probabilistically decide on its role in the clustered network, they cannot guarantee optimal elected set of cluster heads. HEED plays a great role in reducing the energy consumption of the nodes and enhancing the network lifetime. While most of the clustering algorithms focus on the energy balance of the nodes to prolong the network lifetime, the focus of this paper was to improve the energy efficiency of the network and at the same time maximizing the network coverage.

Further the paper proposed by [12] it is DEECIC (Distributed Energy-Efficient Clustering with Improved Coverage), a distributed clustering algorithm that considers both energy and topological features of the sensor network. DEECIC offers a feasible and efficient solution to handle large-scale networks with their enhancements to better assign unique IDs to sensor nodes, reducing communication expense and improve network coverage. Synchronization of independent of time and without node location information, DEECIC achieves good distribution of cluster heads within the network. DEECIC is also fast and locally scalable: since sensor nodes are energy-constrained, frequently receiving data from common nodes and forwarding them to the base station will consume a large amount of energy on cluster heads, DEECIC can achieve re-clustering within constant time and in a local manner. However the current DEECIC system is based on the assumption that all the sensor nodes and the base station remain stationary.

3. Cluster Formation in Heed Protocol

In this section, we describe the network model. Assume that there are N sensor nodes, which are randomly dispersed within a 100m*100m Rectangular region (Figure 1) and the (Figure 2) shows the cluster formation by HEED protocol.

Cluster head selection is primarily based on the residual energy of each node. Since the energy consumed per bit for sensing, processing and communication is typically known and hence residual energy can be estimated. Intra cluster communication cost is considered as the secondary parameter to break the ties. A tie means that a node might fall within the range of more than one cluster head.

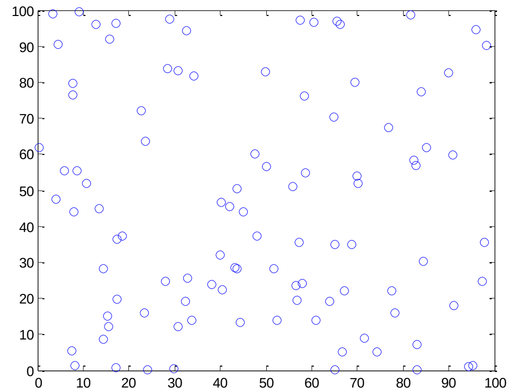


Figure 1. Random Deployment of 100 Sensor Nodes

The lower intra-cluster communication cost is favoured, when there are multiple candidates for cluster heads. The secondary clustering parameters are: intra-cluster communication cost, which is a function of (i) cluster properties, such as cluster size and (ii) whether or not variable power levels are permissible for intra-cluster communication. If the power level used for intra-cluster communication is fixed for all nodes, then the cost can be proportional to (i) $Node\ degree$, if the requirement is to distribute load among cluster heads, or (ii) $1/Node\ Degree$, if the requirement is to create dense clusters. This means that a node joins the cluster head with minimum degree to distribute cluster head load or joins the one with maximum degree to create dense clusters. Each node performs neighbor discovery and broadcasts its cost to the detected neighbors. Each node sets its probability of becoming a cluster head.

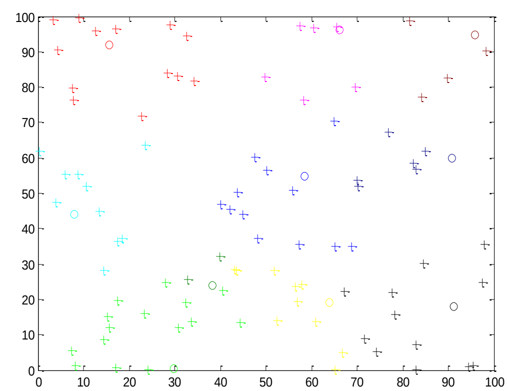


Figure 2. Clusters Formation by HEED Protocol

4. Network Model Assumptions

In case of HEED each node sets its probability of becoming a cluster head, CH_{prob}, as follows:

$$CH_{prob} = max\left(\left(p_i \times \frac{E_{residual}}{E_{max}}\right), T(S_i)\right) \qquad \ldots(2)$$

Where, p_i is the initial percentage of cluster heads among n nodes (it was set to 0.05), while $E_{residual}$ and E_{max} are the residual and the maximum energy of a node (corresponding to the fully charged battery), respectively. The value of CH_{prob} is not allowed to fall below the threshold $T(S_i)$ (i.e. 10^{-4}).

Consider a set of sensors dispersed in a field. Following properties of sensor network have been assumed including the clustering parameters [4] except operation in case of heterogeneity (two-, three- and multi-level) and proposed D-HEED that has been explained afterwards:

- The sensor nodes are quasi-stationary.
- Links are symmetric, i.e., two nodes can communicate using the same transmission power level.
- The network serves multiple mobile/stationary observers, which implies that energy consumption is not uniform for all nodes.
- Nodes are location-unaware, i.e., not equipped with GPS-capable antenna.
- All nodes have similar capabilities (processing/communication) and equal significance. This motivates the need for extending the lifetime of every sensor.
- Nodes are left unattended after deployment. Therefore, battery recharge is not possible. Efficient, energy-aware sensor network protocols are thus required for energy conservation.
- Each node has a fixed number of transmission power levels.
- The radio energy dissipation model is same reported in the literature.
- The energy analysis mentioned in this paper is same as reported in [4]. Therefore, the total energy dissipated in the network is:

$$E_{total} = l \times (2 \times N \times E_{elec} + N \times E_{DA} + (k \times d_{toBS}^2 + N * d_{toCH}^2) \times E_{fs}) \quad \ldots(3)$$

Where N number of sensor nodes are uniformly dispersed in the area A=$M*M$ sq. meters. Let us assume that in each clustering round, there are k cluster, i.e. there will an average of N/k nodes per cluster, that means that a cluster is having one cluster head and (N/k)-1 non-cluster head nodes. d_0 is the Threshold distance of any node to the sink or its cluster head after assuming the base station is at the centre of the field. E_{CH} is the energy consumed by the cluster head in receiving messages from the adjacent nodes, aggregating the messages and sends the aggregated message to the base station during a round. l is the number of bits of transmission message and the d_{toBS} is the average distance between the cluster head and the base station. The non cluster head nodes can only transmit the data to the cluster head during a round. Therefore, the energy consumed by the non cluster head nodes is:

$$E_{non-CH} = l \times E_{elec} + l \times E_{fs} \times d_{toCH}^2 \quad \ldots(4)$$

Where d_{toCH} is the average distance between the node and its cluster head. Assuming that the nodes are uniformly distributed, it can be shown that:

$$d_{toBS} = \int_A (x^2 + y^2) * \frac{1}{A} \, dA = 0.765 * \frac{M}{2} \quad \ldots(5)$$

and

$$d_{toCH} = \int_0^{xmax} \int_0^{ymax} (x^2 + y^2) * \rho(x,y) dx dy = \frac{M}{\sqrt{2\pi k}} \quad \ldots(6)$$

4.1. *Case-I: Multi-level H-HEED (MH-HEED)*

For multi-level H-HEED protocol, initial energy of sensor nodes is randomly distributed over the close set of $[E_0 ,\ E_0 * (1 +\ a_{max})]$, where E_0 is the lower bound and a_{max} determine the value of the maximal energy. Initially, the node s_i is equipped with initial energy of $E_0 * (1 + a_i)$, which is a_i times more energy than the lower bound E_0. The total initial energy of the network [11] is given by:

$$E_{total} = \sum_{i=1}^{N} E_0 * \ (1 +\ a_i) = \ E_0 * \ \left(N + \ \sum_{i=1}^{N} a_i\right) \qquad \ldots(7)$$

The clustering process [4] is triggered after every *TCP* + *TNO* seconds to select new cluster heads. At each node, the clustering process requires a number of iterations, which we refer to as *Niter*. Every step takes time *tc*, which should be long enough to receive messages from any neighbor within the cluster range. The protocol has three main phases, namely the initialization, the repetition and the finalization phases.

In the initialization phase, each node performs neighbor discovery and broadcasts its cost to the detected neighbors. Each node sets its probability of becoming a cluster head, *CHprob*, as follows:

$$CH_{prob} = max\left(\left(p_i \times \frac{E_{residual}}{E_{max}}\right),\ T(S_i)\right) \qquad \ldots(8)$$

Where, C_{prob} is the initial percentage of cluster heads among n nodes (it was set to 0.05), while $E_{residual}$ and E_{max} are the residual and the maximum energy of a node, respectively. The value of CHprob is not allowed to fall below the threshold p_{min} (i.e. 10^{-4}). The value of p_{min} ensures the quick termination of the protocol, while is final CH is a Boolean variable showing whether the node is a final cluster head or not. For using different power levels for intra-cluster communication, Discover neighbors within every power level $Pwr_i \ \leq \ Pwr_c$, where *Pwrc* is the cluster power level and assume that if cluster head *u* can reach a node *v* with power level *l*, then *v* can reach *u* with level *l* as well. Neighbor discovery is not necessary every time, when clustering is triggered. This is because in a stationary network, where nodes do not die unexpectedly, the neighbor set of every node does not change very frequently.

In the repetitive phase, in each iteration, all undiscovered nodes elect to become a cluster head with the CH_{prob}. Each node can advertise itself as a tentative or a final cluster head, if it has the lowest cost among all the known tentative cluster heads (maintained in SCH), or if it has reached the maximum number of iterations (controlled by CH_{prob}). Every node that has heard neither a tentative CH nor a final CH advertisement message announces itself to become a cluster head with probability CH_{prob}. After that each node doubles its CH_{prob} value and iterates this phase until the value of CH_{prob} becomes 1. A tentative cluster head can become a regular node at a later iteration in this protocol, if it finds a cluster head with lower cost. The cost model of HEED is proposed to be proportional to the average minimum reachability power (AMRP), or to the node degree.

At the end in the finalization phase, if a node considers itself "undiscovered" (i.e., it has not heard a final CH advertisement), it announces itself to be a cluster head with final state. This ensures that at the end every node is either a cluster head or a member of cluster.

4.2. Case-II: Proposed D-HEED Protocol Design and Operation

We have introduced the proposed deterministic HEED protocol, whose goal is to increase the lifetime and stability of the network in the presence of heterogeneous nodes. Since cluster heads consume more energy than cluster members in receiving or sensing data from their member nodes, performing signal processing and sending the aggregated data to next node or base station, so the role of cluster head must be rotated among sensor nodes. HEED protocol is operated under multi-level heterogeneous network model, which leads to the introduction of MH-HEED protocol. Therefore, D-HEED works in same way as HEED and also considers how to optimally select the cluster heads in the heterogonous network. D-HEED uses different types of sensors under different levels of heterogeneity and probability weight that decide the threshold $T(S_i)$.

Nevertheless, a modification of the threshold-equation by the remaining energy has a crucial disadvantage: After a certain number of rounds the network is stuck, although there are still nodes available with enough energy to transmit the data to base station. The reason for this is a cluster-head threshold value, which is too low, because the remaining nodes have a very low energy level. A possible solution for this problem is a further modification of the threshold equation. It is expanded by a factor that increases the threshold for any node that has not been cluster head for the last $1/p_i$ rounds:

Therefore in case of Deterministic HEED each node sets its probability of becoming a cluster head, CH_{prob}, as follows:

$$CH_{prob} = max\left(\left(p_i \times \frac{E_{residual}}{E_{max}}\right), T(S_i)\right) \qquad \dots(9)$$

Where the value of $T(S_i)$ may be obtained as:

$$T_{(S_i)} = \frac{p_i}{1-\left(p_i \times \left(r\ mod \frac{1}{p_i}\right)\right)} \times \left[E_{residual} + \left(r_s div \frac{1}{p_i}\right) \times (1 - E_{residual})\right] \qquad \dots(10)$$

The value of CH_{prob} is not allowed to fall below the threshold $T(S_i)$ which is dependent on p_i, $E_{residual}$ and *r is the number of rounds*. Here r_s is the number of consecutive rounds in which a node has not been cluster-head. When r_s reaches the value $1/p_i$ the threshold $T(S_i)$ is reset to the value it had before the inclusion of the remaining energy into the threshold-equation 10. Thus, the chance *to* become *cluster*-head increases because of high threshold value. A possible blockade of the network is solved. Additionally, r_s is reset to 0 when a node becomes cluster-head. Thus, we ensure that data is transmitted to the base station as long as nodes are alive.

4.3. A Set-Up Phase

In every transmission round, each node n uses the formula mentioned in equation 10 to calculate the *T(n)* value and choose a random number between 0 and 1. If this chosen number is less than the calculated threshold *T(n),* then the node becomes a cluster-head. The selected cluster heads broadcast an advertisement message to the network to declare themselves as cluster heads. The node can determine the needed energy to transmit the data to cluster head based on the received strength of signal. Once the nodes decide to which cluster belong, they inform the cluster-head with transmitting a join-request message to it, using CSMA/CA MAC protocol. A header, the node ID and the cluster-head ID, forms this message, which is a short one. This message size grants to reduce the time channel access and the transmission energy cost. Receiving the join- messages from all the nodes, the cluster-head schedule a TDMA allocating a time slot to each cluster's nodes. After that, the cluster nodes are informed by a broadcasted message containing the TDMA schedule. The choice of TDMA technique in the cluster allows a energy saving, because no collisions occurred and the node can go in sleep mode, when it has nothing to transmit, in this way, the clusters are formed.

4.4. Steady-State Phase

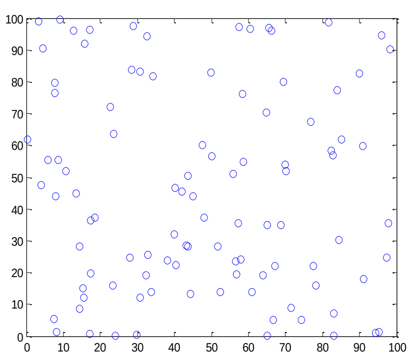
Once the clusters are established, the nodes transmit their data messages towards the cluster-head. Within the cluster, the communication uses TDMA, as described in the set up phase. When the cluster-head receives all the data from nodes, it performs its comparison, to form a new message that sent to the base station.

5. Node Deployment Strategies in case of H-HEED, MH-HEED and D-HEED

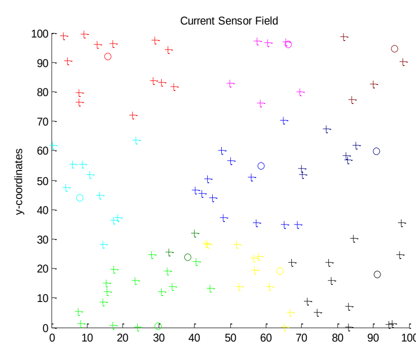
Node deployment is a fundamental issue in Wireless Sensor Networks (WSNs). A proper node deployment scheme can reduce the complexity of problems in WSNs as, for example, routing, data fusion, communication etc. The type of deployment affects are important properties such as the expected node density, node locations, regular patterns in node locations and the expected degree of network dynamics. Furthermore, it can extend the lifetime of WSNs by minimizing energy consumption. In this paper, we have explored random and deterministic node deployments for large-scale WSNs. Here, we have considered two cases: a uniform random and a grid node deployment [15].

5.1. Uniform Random Deployment

In this type of deployment, each sensor node has equal probability of being placed at any point inside a given field. Accordingly, the nodes are scattered on locations, which are not known with certainty. For example, such type of deployment can result from throwing sensor nodes from an airplane. In general, a uniform random deployment is assumed to be easy as well as cost-effective [15]. In this paper, we have considered the uniform deployment of the sensor nodes in Rectangular field and circular field as shown in Figure 3 and 4. We have deployed the sensor nodes in the Rectangular field and circular field. In *Rectangular field area* (Figure 3), we have randomly deployed 100 sensor nodes in 100*100 m^2 field and in the *Circular field area* (Figure 4) we randomly deployed the 100 sensor nodes in the circular field with radius 50 m.



(a)



(b)

Figure 3. Rectangular Field (a) Random Deployment and (b) Cluster Formation

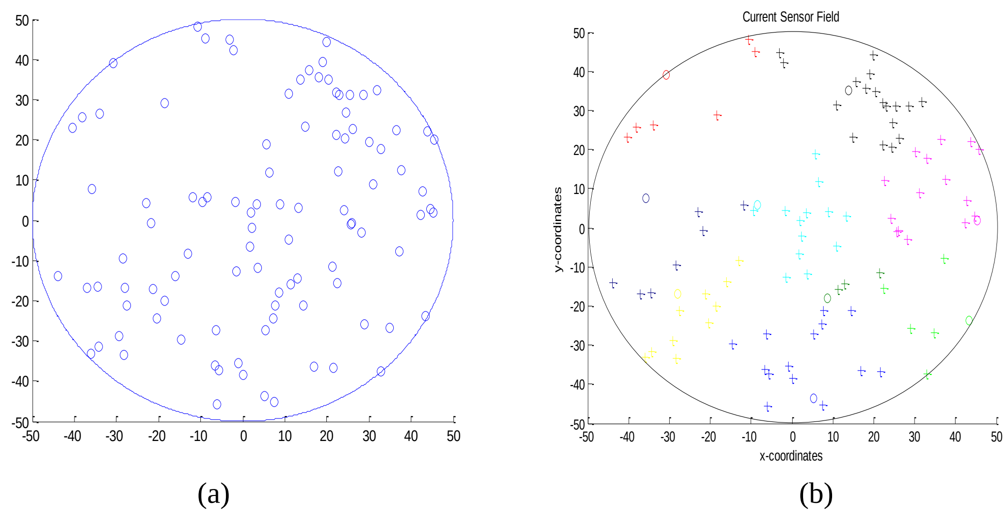


Figure 4. Circular field (a) Random Deployment and (b) Cluster Formation

By using the H-HEED, MH-HEED and D-HEED clustering algorithm, the cluster formed at particular round is represented in figure 3(b) and 4(b) using different colour to represent different cluster and 'o' represents the cluster head and '+' represent the members of cluster.

5.2. Grid Deployment

There are three types of grid deployment depending on the layout namely, a Rectangular, an equilateral triangle and hexagonal as shown in Figure 5. Grid-based deployment is an attractive approach for moderate to large scale coverage-oriented deployment due to its simplicity and scalability [14].

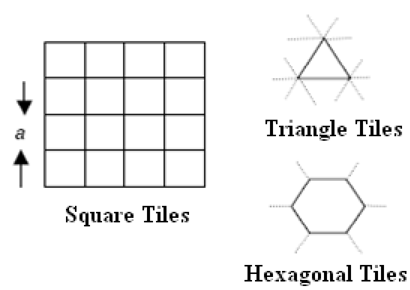
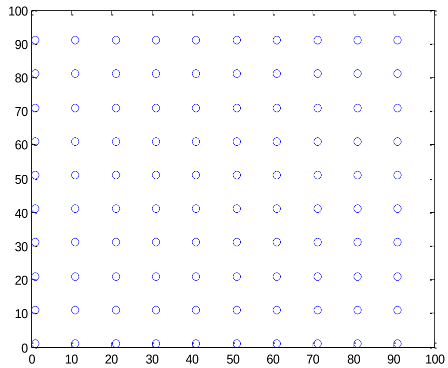
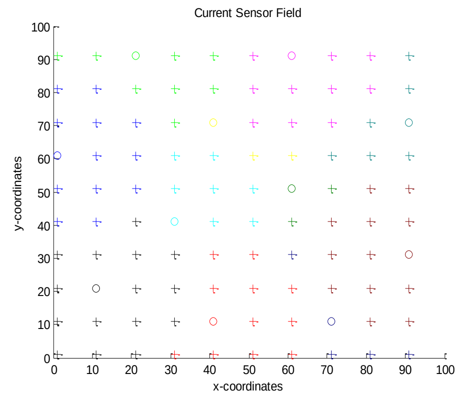


Figure 5. The types of Grid Deployment

Among them, we have considered a Rectangular grid because of its natural placement strategy over a Rectangular area. The sensors are deployed row by row and are controlled to achieve the required distance as shown in Figure 6.



(a)



(b)

Figure 6. Grid Deployment (a) Rectangular Grid Field (b) Cluster Formation

Let N be the number of sensor nodes deployed in grid fashion in the area A. let us assume that the distance between sensor nodes are a. So, the area of a rectangular tile is a^2. Each node will be in corner of four rectangulars. Since a rectangular has four corners, each Rectangular requires a node. There are N nodes, so there are approximately N rectangulars. Each Rectangular has an area of a^2. Therefore, the rectangulars cover an area of $N * a^2$, which must be equal to A [15]. By using the HEED clustering algorithm, the cluster formed at particular round is represented in figure 6(b)and we have deployed 100 sensor nodes in 100*100 m^2 field in grid fashion in Figure 6 (a).

6. Results and Discussions

This section discusses the simulation results of the comparative evaluation of the performance of HEED, MH-HEED and H-HEED in wireless sensor networks. The simulation has done in Matlab. Let us assume the multi-level heterogeneous sensor network with 100 sensor nodes are randomly distributed in the 100m*100m area. The base station is located at the centre (50, 50) and the other parameters used in simulation are listed in the Table I.

Table 1. Simulation Parameters

Parameters	**Values**
Sink	At (50,50)
Threshold distance, d_0	70 m
Cluster Radius	25 m
Energy consumed in the electronics circuit to transmit or receive the signal, E_{elec}	50 nJ/bit
Energy consumed by the amplifier to transmit at a short distance, E_{fs}	10 pJ/bit/m^2
Energy consumed by the amplifier to transmit at a longer distance, E_{mp}	0.0013 pJ/bit/m^4
Data Aggregation Energy, E_{DA}	5 nJ/bit/signal
Message Size	4000 bits
Initial Energy, E_0	0.5 J

In the analysis, we have used the same energy model as proposed in [12]. In the process of transmitting an l-bit message over a distance d, the energy expended by the radio is given by:

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d)$$

$$= \begin{cases} lE_{elec} + lE_{fs}d^2 \\ l\,E_{elec} + lE_{mp}d^4 \end{cases} \quad \ldots(11)$$

And to receive the message, the radio expends:

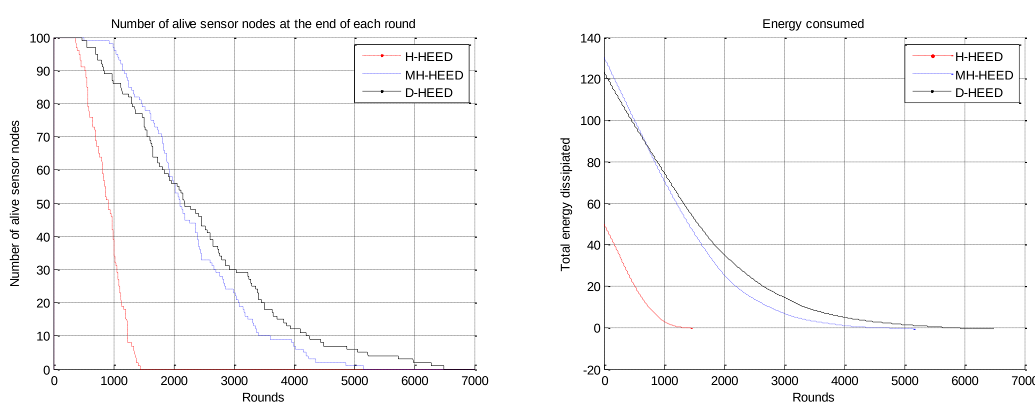
$$E_{Rx}(l) = E_{Rx-elec}(l) = lE_{elec} \quad \ldots(12)$$

The electronics energy, E_{elec}, depends on factors such as the digital coding, modulation, filtering and spreading of the signal, whereas the amplifier energy, $E_{fs}d^2$ or $E_{mp}d^4$, depends upon the distance to the receiver and the acceptable bit-error rate. There are other factors like noise, physical obstacles or collision may affect the received power are ignored.

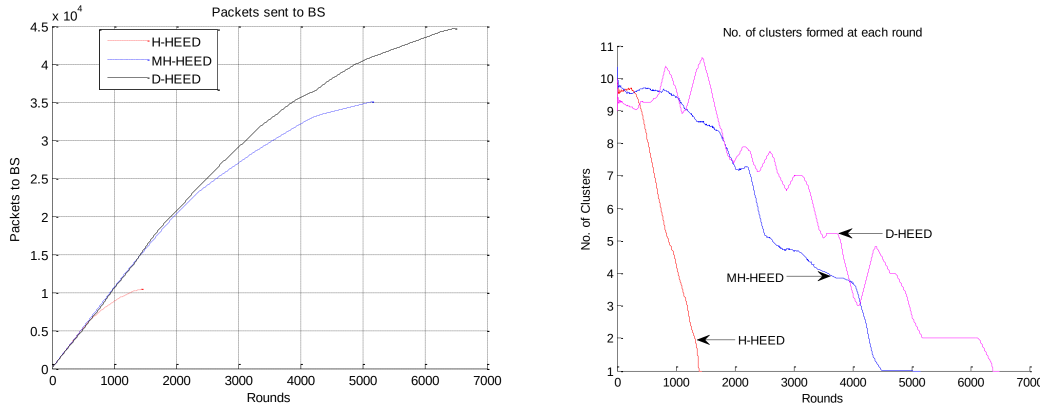
6.1. Case-I (Circular Deplyment):

Here for circular deployment strategy in Figure 7(a) comparative investigations have been reported for H- HEED, MH-HEED and D-HEED and the results ascertain that using by H-HEED, MH-HEED and D-HEED protocol for wireless sensor network all the sensors nodes die after 1400, 5200 and 6500 rounds respectively. Comparing to H-HEED, the node alive rounds increase about 364.3%. D-HEED as an energy balance protocol, the rounds for which the node alive for D-HEED is longer about 25% than that of MH-HEED. It has been observed that by using D-HEED the lifetime of the wireless sensor network has been magnified in circular deployment strategies.

In Figure 7(b) comparative investigations have been reported for H-HEED, MH-HEED and D-HEED for the energy consumption. Here we have observed that energy consumption are in favor of D-HEED protocol, all the nodes have energy up to 6500, 5200 and 1400 rounds in case of D-HEED, MH-HEED and H-HEED respectively. The network remaining energy depletion rate is very high in case of H-HEED. It presents energy depletion slope approximately 0.035, 0.023 and 0.02J/Round in case of H-, MH-, D-HEED respectively. The substantial improvement has been reported in case of D-HEED. The results indicate that the energy depletion rate is slow and stable in case of D-HEED that gives rise to the lifetime enhancement of the network.



(a) (b)



(c) (d)

Figure 7. After each round (a) Number of alive sensor nodes (b) Total energy dissipated (c) Total number of packets transmitted to BS (d) Total number of Cluster Formation

Similarly, in Figure 7(c), we can observe that the packets sent are higher in case of D-HEED if compared with H- HEED and MH-HEED. Here we have observed that the packets sent to BS are upto 6500, 5200 and 1400 rounds with D-HEED, MH-HEED and H-HEED protocols respectively. Here also the results are in favor of D-HEED protocol. We have observed that the number of messages received at the BS varies linearly at the rate of 10 packets per round for all the cases, for first 2900, 1900 and 900 rounds in case of D-HEED, MH-HEED and H-HEED respectively. While thereafter the results indicate the slope in all the cases due to the reason that the number of death of nodes increases quickly and cosiquently the rate of data transfer to BS decreases. Overall comparitive performance indicate that the D-HEED protocol is suprier to others and there is 300% and 45% improvement in the overall packet transmission over H-HEED and MH-HEED.

Here in Figure7(d) the comparison of number of cluster formation per round for all cases has been mentioned. The results establish that the frequency of cluster formation in D-HEED protocol is very high and this formation is extended upto the 6500 rounds. This is due to the reason that the proposed D-HEED protocol is energy adaptive and optimize the cluster formation by taking the advantage of deterministic threshold level, which is dependent on residual, average energy of nodes and cosiquently cluster formation frequency increases that leads to increase the lifetime of the network. Whereas the formation of cluster head is up to 5200 and 1400 rounds in case of MH-HEED and H-HEED protocols.

6.2. Case-II (Grid Deployment):

In Figure 8, here comparative investigations have been reported for H-HEED, MH-HEED and D-HEED for Grid deployment strategy. In figure 8(a) for H-HEED, MH-HEED and D-HEED protocols the lifetime of sensor nodes are upto the 1600, 4800 and 5900 rounds respectively. In this case (D-HEED) comparing to H-HEED, the node alive rounds increase by 268.7%. D-HEED as an energy balance protocol, the node alive rounds of D-HEED is longer about 22.9% than that of MH-HEED.

Similarly in figure 8(b) comparative investigations have been reported for H-HEED, MH-HEED and D-HEED for the energy consumption and here, we have observed that energy consumption are favored in case of D-HEED protocol, all the nodes have energy upto 5900 rounds, whereas in case of MH-HEED all the nodes have energy upto 4800 rounds and in case of H-HEED protocol all nodes have energy upto1600 rounds. Further it presents the slope approximately 0.031, 0.02 and 0.017J/Round respectively for H-HEED, MH-HEED and D-HEED. Here also the substantial improvement has been reported in case of D-HEED protocol.

In Figure 8(c) , shows packets sent to BS has been investigated by using all the three protocols. Here, we have observed that the packet sent to BS upto the rounds of 5900 in case of D-HEED protocol, whereas in MH-HEED it is upto 4800 rounds and in case of H-HEED protocol it is upto1600 rounds. An overall improvement of 239.3% and 58.3% in the packet transmission to BS has been observed for the proposed D-HEED protocol over the H-HEED and MH-HEED respectively.

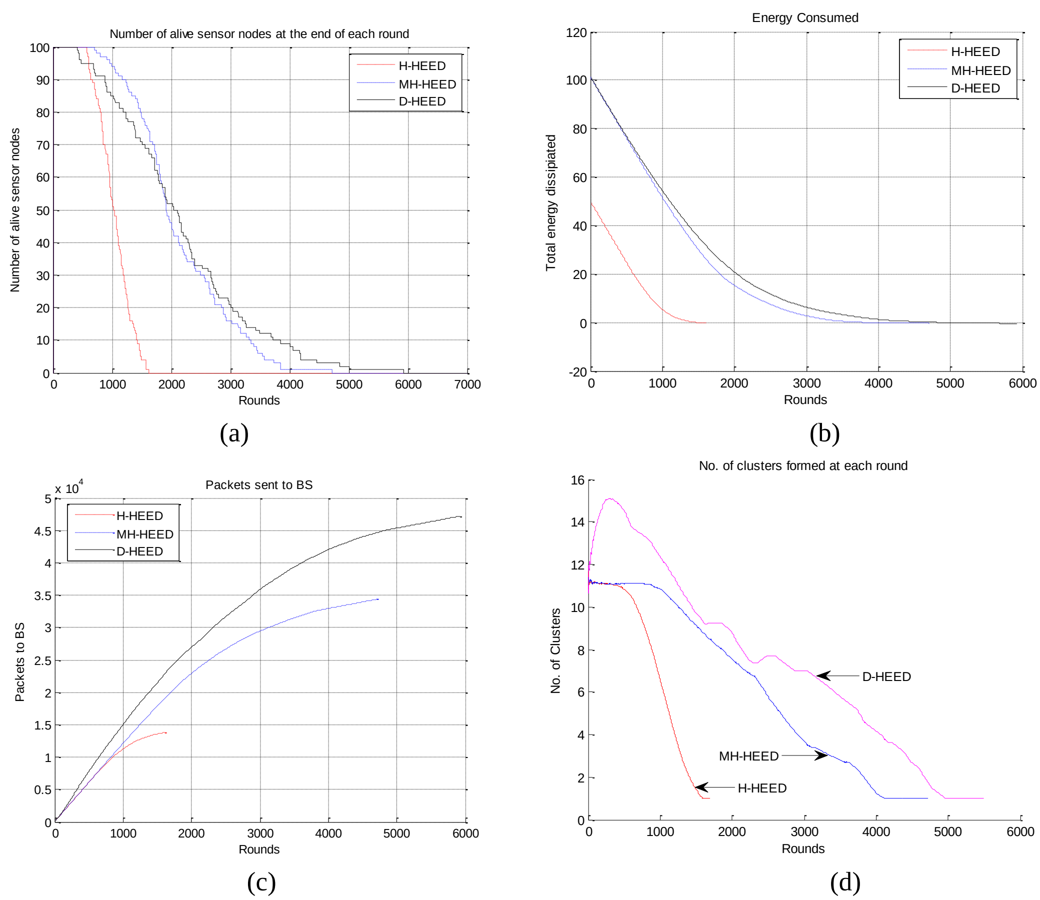


Figure 8. After each round (a) Number of alive sensor nodes (b) Total energy dissipated (c) Total number of packets transmitted to BS (d) Total number of Cluster Formation

In Figure 8(d) we have reported the cluster formation by using MH-HEED, H-HEED and D-HEED and we have observed that it is better in case of D-HEED protocol and which is upto almost 5900 number of rounds, whereas in in case of MH-HEED it is upto 4800 rounds and in case of H-HEED cluster formation is upto 1600 rounds.

6.3. Case-III (Rectangular Random Deployment)

In case of Rectangular Random Deployment comparative investigations have been reported for H-HEED, MH-HEED and D-HEED and investigation has been reported that in Figure 9(a) all the nodes die after 1500, 5200 and 6000 rounds by using H-HEED, MH-HEED and D-HEED protocols respectively. So the observations ascertain that by using D-HEED the lifetime of all sensors nodes are magnified for a network in case of rectangular random deployment strategy.

In Figure 9 (b) the comparative investigations have been reported for H-HEED, MH-HEED and D-HEED for the energy consumption and here we can see that energy consumption are almost same by using D-HEED and MH-HEED protocol, whereas all the nodes have energy up to 6000 rounds and in case of H-HEED all nodes have energy up to 1500 rounds. So it presents the energy depletion slope rate approximately 0.033, 0.023 and 0.02J/Round respectively for H-HEED, MH-HEED and D-HEED. There is substantial improvement in D-HEED protocol over H-HEED, MH-HEED.

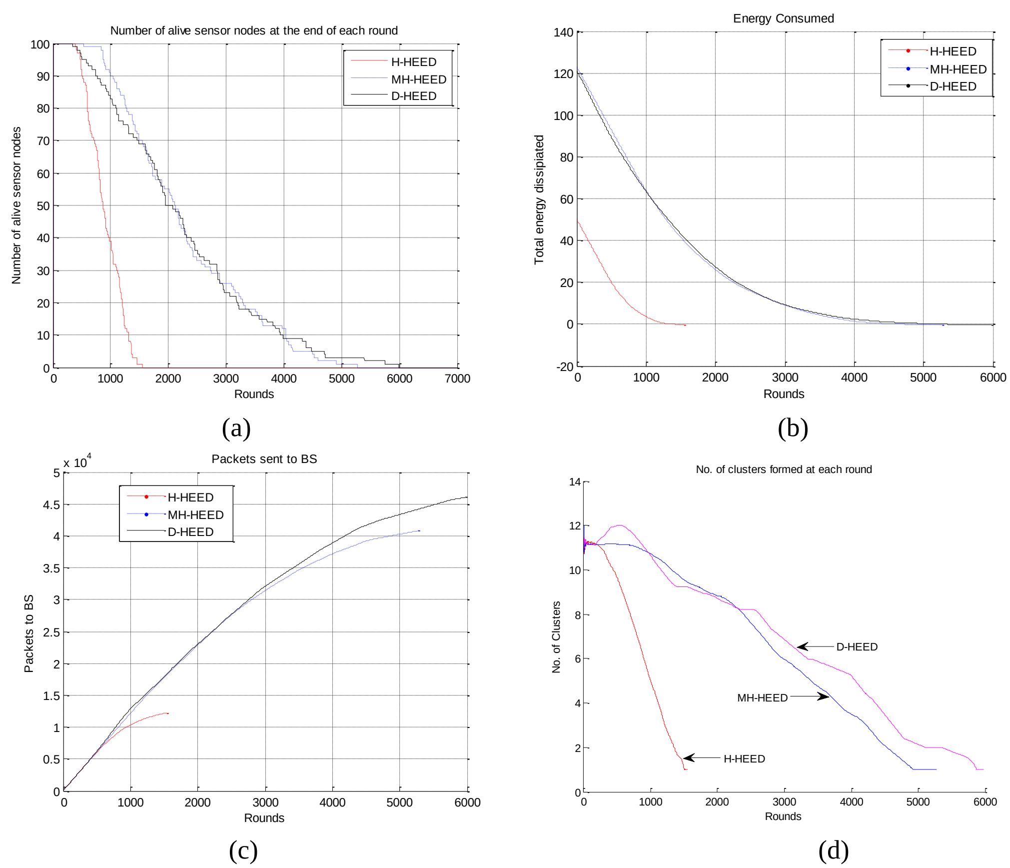


Figure 9. After each round (a) Number of alive sensor nodes (b) Total energy dissipated (c) Total number of packets transmitted to BS (d) Total number of Cluster Formation

Figure 9(c) shows the number of data packets received by the BS during the life time of the network for all the three protocols. Here also we have observed that in case of D-HEED protocol the packet sent to BS is upto the rounds of 6000, whereas in MH-HEED it is upto 5200 rounds and in case of H-HEED protocol it is upto 1500 rounds. Here the packet transmission is increased by 12.19% and 268% using D-HEED protocol in comparison with MH-HEED and H-HEED protocols. Figure 9(d) indicate the cluster formation by using MH-HEED, H-HEED and D-HEED and we have observed that performance is better in case of D-HEED protocl and which is stable up to almost 6000 number of rounds, whereas in case of MH-HEED and H-HEED it is upto 5200 and 1600 rounds.

7. Conclusions

In this paper, we have evaluated the performance of H-HEED. MH-HEED and D-HEED by introducing heterogeneity and three types of deployments strategies in the wireless sensor networks. The results establish that the proposed D-HEED protocol prolongs the network lifetime and it is energy efficient over the H-HEED and MH-HEED. Comparing to D-HEED over H-HEED, the number of rounds for which the node alive increases about 364.3%, 268.7% & 300% whereas this increase is about 25%, 22.9% &15.38% over MH-HEED in case of circular, grid and rectangular deployment strategies respectively. The D-HEED protocol proved to be an energy balance protocol, here the rounds for node alive is longer than that of H-HEED and MH-HEED. Overall comparitive performance establish that the D-HEED protocol is suprier to others and there is 300%, 239.3% & 268% improvement in the overall packet transmission over H-HEED and 45%, 58.3% & 12.19% over MH-HEED in case of circular, grid and rectangular deployment strategies respectively.The results also ascertain that the energy depletion rate is slow and stable in case of D-HEED over H-HEED and MH-HEED and this gives rise to the lifetime enhancement to the network. Further, the results establish that cluster formation in D-HEED protocol is very smooth and whereas the formation of cluster head is not stable in case of MH-HEED and H-HEED protcols.

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