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On Proficiency of HEED Protocol with Heterogeneity for Wireless Sensor Networks with BS and Nodes Mobility

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ABSTRACT
In this paper, the enhancement of HEED protocol to support mobility in both homogenous and heterogeneous network [Homogeneous HEED (H-HEED), two-, three-level heterogeneous (2H-HHED & 3H-HEED) and multi-level heterogeneous HEED (MH-HEED)] has been presented. Here, we have examined the performance of HEED, 2H-HEED, 3H-HEED and MH-HEED with random mobility in wireless sensor network in terms of stability, energy efficiency, lifetime and throughput. The results establish that the MH-HEED in sensor network proved to be superior because of the enhancement in the performance metrics like: stability, lifetime and throughput (data packets transmitted to BS) with the random mobility of BS. The network performance is dominating in terms of stability, throughput and energy efficiency if 3H-HEED protocol is used and it is useful for habitat monitoring and other similar applications. The overall performance of the network substantially improved in case of BS mobility.

Keywords
Wireless Sensor Network, Network Lifetime, Heterogeneity, Mobile BS.

1. INTRODUCTION
Typically the WSN contains an important number of inexpensive power constrained sensors, which collect data from the environment and transmit them towards the base station. 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, processing, communicating 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 node bases its decisions on its mission, the information it currently has its knowledge of computing, communication and energy resources. 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 BS is a master node and data sensed by the network is routed back to a BS. The BS is a larger computer where data from the sensor network will be compiled and processed. The BS 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 BS.

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 neighbors) are only used as secondary parameters to break tie between candidate and cluster heads, as a metric for cluster selection to achieve load balancing. In this all 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 - this is the case of heterogeneous sensor networks. As the lifetime of sensor networks is limited and 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. Each node sets its probability of becoming a cluster head, CH_{prob}, as follows in[4]:

$$CH_{prob} = max\left(C_{prob} \times \left(\frac{E_{residual}}{E_{max}}\right), p_{min}\right) \quad \ldots(1)$$

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 (corresponding to the fully charged battery), respectively. The value of CH_{prob} is not allowed to fall below the threshold p_{min} (i.e. 10^{-4}).

The remainder of the paper is organized as follows. In Section 2, describes the heterogeneous network model. Section 3 describes the cluster formation and node mobility in WSN. Section 4 shows the results of H-, 2H-, 3H- and MH-HEED and comparison thereof. Finally, Section 5 gives concluding remarks.

2. HETROGENOUS NETWORK MODEL
In 2-level heterogeneous model described in [5] has been used and therefore the total initial energy of the network is given by:

$$E_{total} = N \times (1 - m) \times E_0 + N \times m \times E_0 \times (1 + a) = N \times E_0 \times (1 + am) \quad \ldots(2)$$

Where 'N' are the number of sensor nodes deployed in a field. E_0 is the initial energy of the normal nodes, and m is the fraction of the advanced nodes, which own a times more energy than the normal ones. Thus there are *m*N* advanced nodes equipped with initial energy of $E_0 \times (1 + a)$, and $(1 - m) \times N$ normal nodes equipped with initial energy of E_0. So, this type of networks has *a*m* times more energy and virtually *a*m* more nodes.

In 3-level H-HEED protocol three types of sensor nodes, i.e. the super nodes, advanced nodes and the normal nodes are considered as described in [6, 7], and the total energy in this case is:

$$E_{total} = N * E_0 * (1 + m * (a + m_0 * \beta)) \quad \ldots(3)$$

Here, m be the fraction of the total number of nodes N, and m_0 is the percentage of the total number of nodes $N * m$ which are equipped with β times more energy than the normal nodes, called as the super nodes, the number is $N * m * m_0$. The rest $N * m * (1\text{-}m_0)$ nodes are having a times more energy than the normal nodes, being called as advanced nodes and the remaining $N * (1\text{-}m)$ nodes are the normal nodes. E_0 is the initial energy of the normal nodes. The energy of the each super node is $E_0 * (1 + \beta)$ and the energy of each advanced node is $E_0 * (1 + a)$.

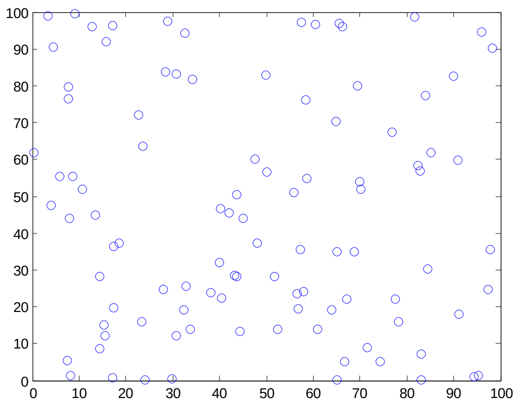
In multi-level H-HEED protocol, initial energy of sensor nodes is randomly distributed over the close set of $[E_0 , E_0 *$ *1+ amax*, where E_0 is the lower bound and a_{max} determine the value of the maximal energy. Initially, the node s_i is equipped with initial energy of $E_0 * (1 + a_i)$, which is a_i times more energy than the lower bound E_0. The total initial energy of the network [6] is given by:

$$E_{total} = \sum_{i=1}^{N} E_0 * (1 + a_i) = E_0 * (N + \sum_{i=1}^{N} a_i) \quad \ldots(4)$$

During Cluster formation phase, every node will have its own E_{max} value in case of heterogeneity while computing the cluster head probability of the sensor node.

3. CLUSTER FORMATION AND NODE MOBILITY IN WSN

We have assumed that there are N sensor nodes, which are randomly dispersed within a 100m*100m square region as depicted in Fig. 1(a). The assumptions made regarding the network models are: Nodes in the network are quasi-stationary, Nodes locations are unaware i.e. it is not equipped by the GPS capable antenna, Nodes have similar processing and communication capabilities and equal significance, Nodes are left unattended after deployment. The cluster formation by HEED protocol is shown in Fig. 1(b).



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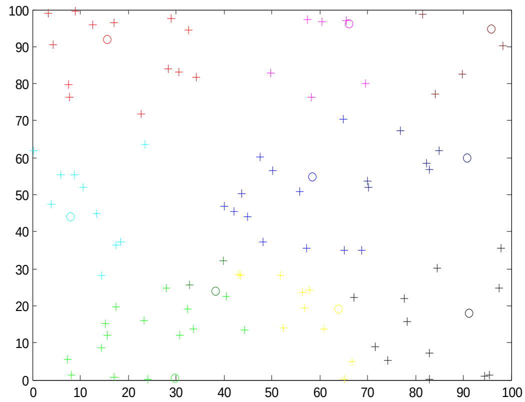
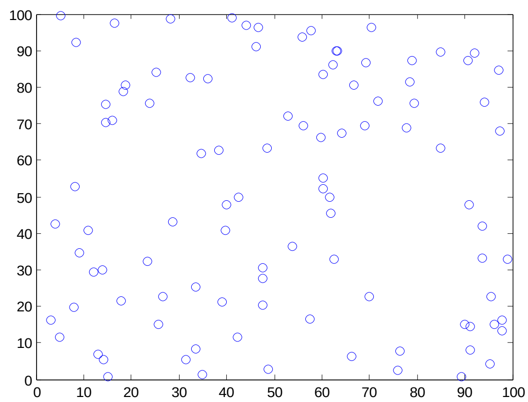


(b)

Fig 1: (a) Random Deployment of 100 Sensor Nodes (b) Cluster Formation by HEED protocol

In wireless sensor network, all the routing algorithms currently available are taking the assumption that the sensor nodes are stationary. Some recent applications of sensor-nets (e.g. in medical care and disaster response) make use of mobile sensor nodes. Mobility improves the coverage of wireless sensor networks [8]. In this paper, we have examined the performance of H-, 2H, 3H- and MH-HEED with either mobility of nodes or BS. We also assume that speed of mobile nodes moving in the network is neither too high nor too low but it's moderate. By this we mean that the nodes don't move continuously but with different pause time. A mobile sensor network is composed of a distributed collection of *nodes*, each of which has sensing, computation, communication and locomotion capabilities [9].

Mobility has motivated to extend the work because the sensor nodes may change their location after initial deployment due to environmental influences such as wind or water, sensor nodes may be attached or carried by mobile entities, and sensor nodes may possess automotive capabilities. In other words, mobility may be either an incidental side effect, or it may be a desired property of the system (e.g., to move nodes to interesting physical locations), in which case mobility may be either active (i.e., automotive) or passive (e.g., attached to a moving object not under the control of the sensor node) [8]. Mobility may apply to all nodes within a network or only to subsets of nodes. The actual speed of movement may also have an impact, for example on the amount of time during which nodes stay within communication range of each other.



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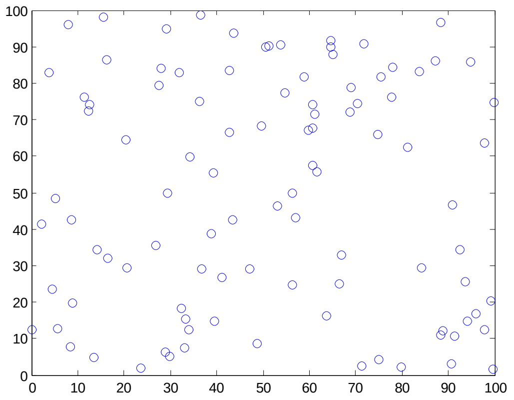


(b)

Fig 2: Deployment of the Mobile Sensor Nodes in Network (a) Initial (b) After Mobility in few Rounds

This paper mainly focused on either mobility of nodes or BS for WSN because earlier reported HEED Protocol makes an assumption that all the sensor nodes is stationary. In this paper, we have investigated the performance of HEED protocol by making use of mobility in homogenous and heterogeneous networks.

4. RESULTS AND DISCUSSIONS

The simulation is done by using matlab and a sensor network of 100 nodes is distributed in the 100m*100m area. The BS is located at the centre (50, 50). We have set the minimum probability for becoming a cluster head (p_{min}) to 0.0001 and initially the cluster head probability for all the nodes is 0.05. The parameters used for simulation are listed in the Table 1. For the analysis, we have used the energy model proposed in [7].

Table 1: Simulation Parameters

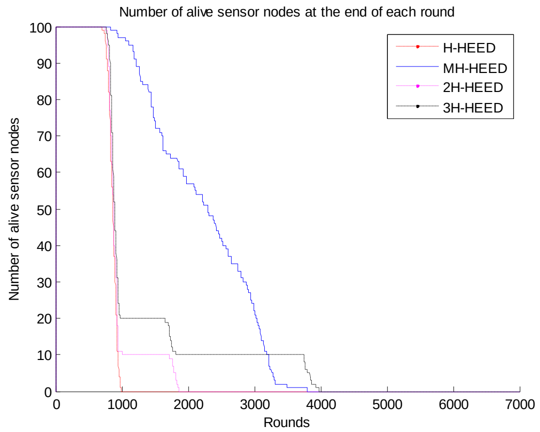
Parameters	Values
Sink	At (50,50)
Threshold distance, d_0	70 m
Cluster Radius	25 m
Energy consumed in the electronics circuit to transmit or receive the signal, E_{elec}	50 nJ/bit
Energy consumed by the amplifier to transmit at a short distance, E_{fs}	10 pJ/bit/m^2
Energy consumed by the amplifier to 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

For simulation, we have deployed 30 advanced nodes (m = 0.3) with 2.5 times more energy than normal nodes (a = 1.5) in case for 2H-HEED, whereas for 3H-HEED, there are 30 advanced nodes deployed with 2.5 times more energy than normal nodes and 20 super nodes deployed with 4 times more energy than the normal nodes. However, for MH-HEED each node in the sensor network is randomly assigned different energy between a closed set [0.5, 2]. The detailed behavior of H-, 2H-, 3H- and MH-HEED protocol is illustrated by considering two different cases of mobility either nodes or BS as mentioned below:

4.1. Case-I: Moving Nodes

From the Fig. 3(a) indicates the number of alive nodes with respect to number of rounds. It has been observed that the network nodes are alive up to 1000, 1900, 3800 and 4000 rounds by using H-, 2H-, MH- and 3H-HEED respectively. There is significant improvement in the lifetime of the network by using random walk of the nodes, but the Fig. 3 (a) shows that MH-HEED proved to be more stable over the other protocols. The results ascertain that there is 300%, 110% and 5.26% improvement in network lifetime by using H-, 2H-, MH- and 3H-HEED respectively. Fig. 3(b) depicts that the cluster formation stability is very high in the network by using MH-HEED protocol.

The total energy dissipation with respect to number of rounds has been indicated in Fig. 3(c). Here it has been observed that the total energy depletion of the network is after 1000, 1900, 3800 and 4000 rounds by using H-, 2H-, MH- and 3H-HEED respectively. The energy consumption slope of the network is 0.05, 0.029, 0.032 and 0.0175 J/Round by using H-, 2H-, MH- and 3H-HEED respectively. It is observed that the energy consumption is low in case of 3H-HEED over the other protocols. As shown in Fig. 3(d), we represent the number of data messages received at the base station per round.



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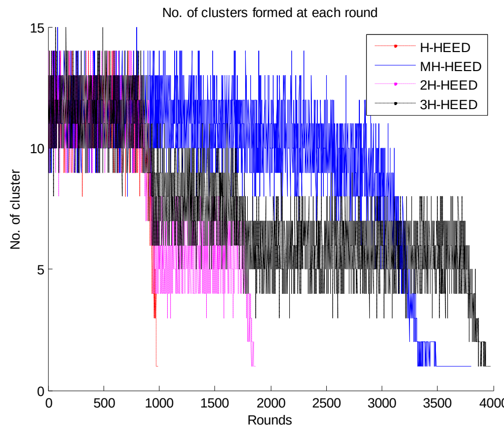

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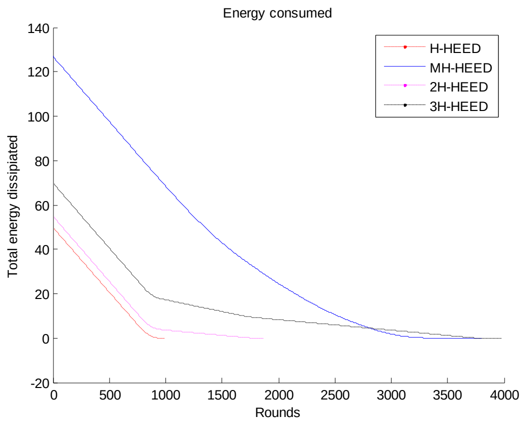

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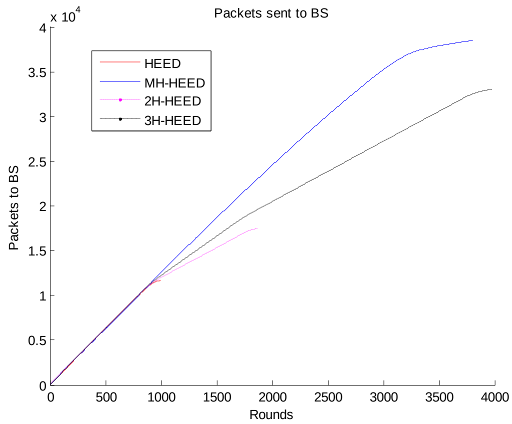


(d)

Fig 3: After each round (a) Number of Alive nodes (b) No. of cluster heads (c) The total energy dissipation (d) Number of packets sent to BS per Round in Wireless Sensor Network

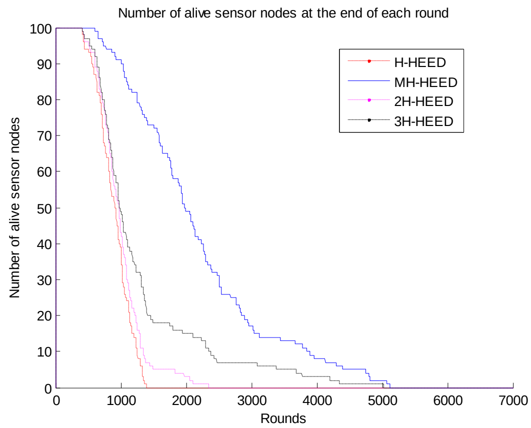
The Fig 3(d) also justify the above reported findings by indicating that the number of data packets transmitted to BS are significantly high and this is 240.9%, 150% and 20.96% higher by using MH- over H-, 2H- and 3H-HEED respectively. We have observed that number of messages received at the BS varies linearly for all the cases, for the first 1000 rounds. After that, we have observed a stagnation of this number for H-HEED and 2H-HEED network. The reason is that the number of death nodes increases quickly and consequently the number of messages transmit towards the BS decreases.

Here, the observations reveal that there is tradeoff in performance of the network by making random walk of the nodes. It has been noticed that MH-HEED protocol gives the high stability and throughput (Number of data packets transmitted to BS) while, energy dissipation and lifetime is more in case of 3H-HEED.

5.2. Case-II: Moving BS

In Fig. 4(a), we introduced the improved characteristic with moving BS under HEED protocol. We observe that the unstable region of H-, 2H- & 3H-HEED is larger than MH-HEED. It is because the super and advanced nodes die more slowly than normal nodes in 2H-, 3H- & MH-HEED network. For the reason that MH-HEED takes into account both the initial and residual energy therefore, the stability period of MH-HEED is much longer than that of other cases. Moreover, we have observed that MH-HEED takes some advantage in terms the death of first and last node, which gives rise to enhance the stability of the network. It has been observed that in H-HEED network the death of the first and last sensor node is after 500 to 1500 rounds respectively. However, for 2H-, 3H- & MH-HEED network the last node alive after 2500, 5000 and 5100 rounds respectively. In case of moving BS the MH-HEED network proved to be better because the death of first and last is after 950 and 5100 rounds. Random movement of BS reveals that there is improvement in the network lifetime for the MH-HEED network. Certainly, this change in the performance is due to the modifications in the simulation setup and because the protocol introduces a random BS mobility. Fig. 4(b) depicts that the cluster formation stability is very high in the network by using MH-HEED protocol over the other protocols.

Fig. 4(c) gives the total network remaining energy in every transmission round. Here, we have observed the energy level of nodes for particular rounds of simulation. The network remaining energy decreases rapidly in H-HEED, 2H- & 3H-HEED protocols. The energy dissipation presents a slope approximately 0.033J/Round in H-HEED WSN, compared to 0.022, 0.014 and 0.023J/Round in 2H-, 3H- and MH-HEED protocols respectively.



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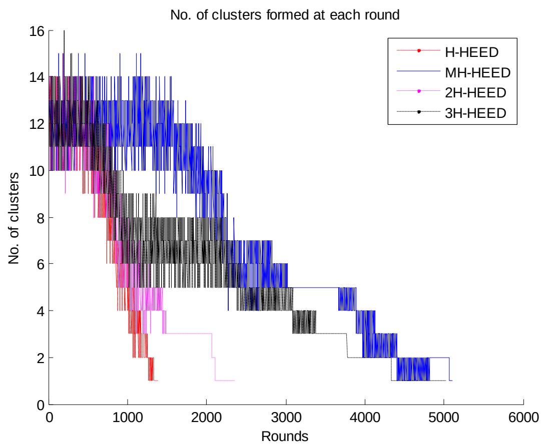

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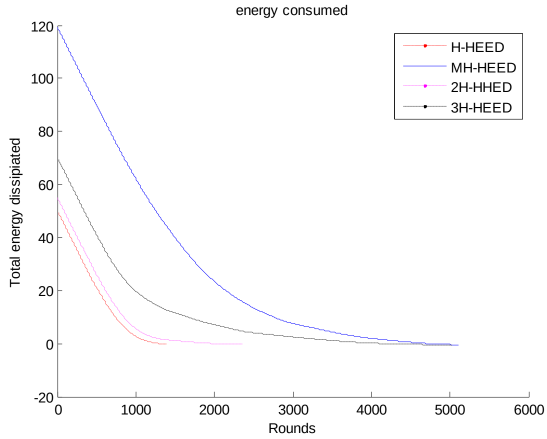

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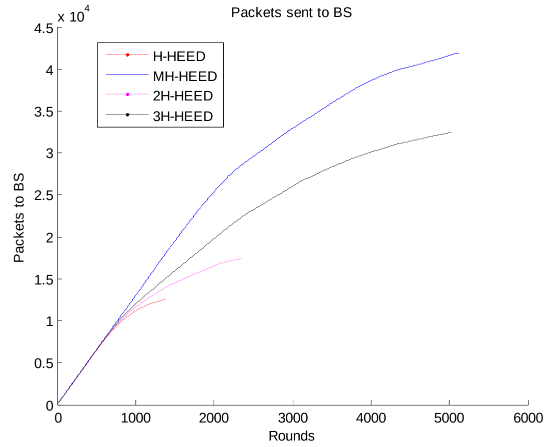

(d)

Fig. 4 After each round (a) Number of Alive nodes (b) No. of cluster heads (c) The total energy dissipation (d) Number of packets sent to BS per Round in Wireless Sensor Network

The network energy depletion is fast in H-, 2H- and MH-HEED in comparison with 3H-HEED protocol. The significant improvement has been observed in 3H-HEED and MH-HEED network in terms of energy efficiency, but in H-HEED and 2H-HEED network energy depletes at very fast rate.

As shown in Fig. 4(d), we represent the number of data packets transmitted to the BS. We have observed that the number of packets transmitted to BS varies linearly up to first 800 transmissions of rounds for all cases and thereafter, we have observed a stagnation of this number for H-HEED and 2H-HEED. Moreover, we can perceive that, when the entire nodes of network are dead, the total number of messages transmitted to the BS is considerable for the 3H-, and MH-HEED protocol. There is considerable hike in the packet transmission that is 241.66%, 156.25% and 36.66% by using MH- over H-, 2H- and 3H-HEED respectively. These overall results establish that MH-HEED is more proficient than H-, 2H- and 3H-HEED for mobile BS in terms of stability, throughput and lifetime but energy efficiency slope is 64.28% low in comparison with 3H-HEED.

5. CONCLUSIONS

In this paper, H-, 2H, 3H- and MH-HEED protocol with random mobility of either nodes or BS has been proposed for wireless sensor network. Here, the performance comparison is done with different level of heterogeneity like: 2-, 3- and multi-level network. The simulation results establish that the node mobility gives rise in stability and throughput of a MH-HEED while, it is in terms of lifetime & energy efficiency slope by using 3H-HEED protocol. On the other hand the BS mobility gives rise to lifetime, stability and throughput, whereas it is in the form of energy efficiency slope in 3H-HEED network. It is identified that either the mobility of nodes or BS enlarges the performance of MH- and 3H-HEED protocol over the others.

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