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Advanced Sep-E Protocol for Extending the Lifetime of the Heterogeneous Wireless Sensor Networks

Arwinder Kaur[1], Simranjit Singh[2], Kanwaljit Singh[3]
[1]Student, India, arwinder1989@gmail.com
[2]Student, India, simrangrewal55@gmail.com
[3]Professor, India, kjitsingh@ymail.com

ABSTRACT

Due to the increasing demand of WSNs, they are progressively more prepared to do the more complex functions, but it still requires battery operated sensors to use the constrained energy in order to enhance the lifetime of the network. There are many hierarchical protocols that use the clusters to coordinate the consumption of energy in WSNs. In this paper, mainly the heterogeneous clustered energy efficient protocols are discussed. A modified clustering algorithm is proposed with four-tier sensor nodes setting, to deal with the energy heterogeneity among sensor nodes.

Key words: Clustering Algorithm, Heterogeneous Protocols, Lifetime and Wireless Sensor Network.

1. INTRODUCTION

A typical wireless sensor network consists of large number of sensor nodes. Each node consists of microcontroller fixed with a node and some way of communication i.e. radio [1]. Sensor nodes or motes in WSNs are small sized and able of sensing, collecting and processing data while communicating with other connected nodes in the network, via radio frequency (RF) channel.

Each of the sensor nodes consists of mainly four components [1]: Sensing Unit, Processing Unit, Power Unit and Transceiver Unit. Nodes in sensor network are battery-operated and most frequently constrained in the energy is the lack of ability of recharging the nodes. So, one of the most important issue is the energy consumption in the design of the protocol. Design should able to balance the lifetime of the network. Lots of studies have been carried out on WSNs [1], [2], [3], [9]-[12] showing that this technology is continuously finding new application in several areas, like hostile and remote regions as seen in military for battle surveillance, monitoring the enemy activity, detection of attacks and security propriety.

A modified clustering algorithm is proposed in this paper with four-tier sensor nodes setting, to deal with the energy heterogeneity among sensor nodes. This approach is an improvement to the SEP-E protocol that used the three-tier node setting. There is a significant improvement in the performance of the network with proposed protocol in terms of increase in number of rounds that leads to enhance the network lifetime.

The remaining part of this paper is organized as follows. In section 2, we briefly review related work in this field. Then we discuss network model used for this protocol in section 3. We discuss our proposed clustering technique in section 4. In section 5, we present our advanced SEP-E protocol. The simulation results are presented in section 6. Finally, we conclude the paper and future directions are given for the improvement in WSN.

2. RELATED WORK

Many clustering techniques have been employed to deal with energy management in WSNs. LEACH (Low Adaptive Clustering Hierarchy) is a clustering based protocol that utilizes the randomized rotation of cluster heads to evenly distribute the energy load among the sensor nodes in the network [4]. The sensor nodes organize themselves into clusters using a probabilistic approach to randomly elect themselves as heads in an epoch. But, LEACH protocol is not heterogeneity-aware, there is an energy imbalance between the nodes in the network, the sensor nodes die out faster than normally should have if they were to maintain their energy uniformly, thus, introduces energy imbalance. LEACH assumes that the energy of all the nodes is same.

The authors in SEP [5] were the first one to address the impact of energy heterogeneity of nodes in WSNs that are hierarchically clustered. They assigned weighted probability to each node based on its' energy level as the network evolves. One of the characteristic of this is that it rotates the cluster head to adapt the election probability to suit the heterogeneous setting. In this model, there are two types of nodes i.e. normal nodes and advanced nodes with different energy levels, constituting WSN in single-hop setting. Nodes are not mobile and are uniformly distributed over the sensing area.

H-SEP is the proposed new protocol, which is the combination of SEP [5] and HEED [6] protocols. HEED protocol is the clustering protocol. It uses the residual energy as the primary parameter and network topology features are used only as secondary parameters to break tie between candidate cluster heads, as a metric for cluster selection to achieve load balancing. A tie means that a node can fall within the range of more than one cluster heads.

A new protocol called Deterministic-SEP (D-SEP) was proposed in [7], which is the extension of SEP protocol, for electing cluster heads in a distributed manner in two-, three-, and multi-level hierarchical WSNs. They introduced a superior characteristic in this proposed protocol and discussed the cluster head selection algorithm by describing the threshold and probability equations. Therefore, D-SEP works in rounds as in SEP and also considers how to optimally select the cluster heads in the heterogeneous WSN. At each round node decides whether to become a cluster head or not based on the threshold calculated by the percentage of suggested cluster heads for the network and the number of times the node has been a cluster head so far. This decision is made by choosing the random number between 0 and 1. If this number is less than the threshold, the node will become CH for the current round.

The proposed protocol SEP-E in [8] is an extension to SEP protocol by considering three energy levels in two hierarchy settings which is the first improvement to SEP. The modified scheme optimizes the stable region of the network system by further increasing the epoch to accommodate the additional energy level introduced in this work. In this new additional node called ‘intermediate nodes’ are introduced into the system, to cater the multi-node diversity. The ‘intermediate nodes’ has the energy less than advanced odes. Mathematically, the energy can be described as $E_0 < E_{int} < E_{adv}$. As in SEP protocol the energy of the normal nodes is E_0, for intermediate nodes is $(1+\beta)$ E_0, for advanced nodes is $(1+\alpha)$ E_0, where β *and* α are the energy factor of the intermediate, advanced nodes respectively.

We present an extension of this approach called advanced SEP-E (ASEP-E), by considering four types of nodes which we refer to as four tiers in-clustering, in two level hierarchy network. Our new node type for this network is referring to as “super advanced nodes”. Now, the current goal is to achieve a robust self-configured WSN that maximizes the lifetime of the network.

3. NETWORK MODEL

In this, radio energy dissipation model used is same as in LEACH protocol [4], as shown in Figure 1. The first assumption in this is that the radio model dissipates E_{elect}=50nJ to both transmitter and receiver circuits. The second assumption is that both Friss free space (fs) and multipath (mp) losses depends upon the Transmitter amplifier model and on respective node distances (d). Therefore, to transmit k bits of data, the energy can be calculated as:

$$E_{Tx}(k, d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k,d) \quad (1)$$

$$= \begin{cases} kE_{elec} + k\epsilon_{fs}d^2, & d < d_0 \\ kE_{elec} + k\epsilon_{mp}d^4, & d \geq d_0 \end{cases}$$

where, $d_0 = \sqrt{\epsilon_{fs}/\epsilon_{mp}}$ (2)

$E_{Tx\text{-}elec}$ is the energy used by the transmitter electronics to send the k bits of data.

$E_{Tx\text{-}amp}$ is the energy used by the amplifier to send the k bits of data.

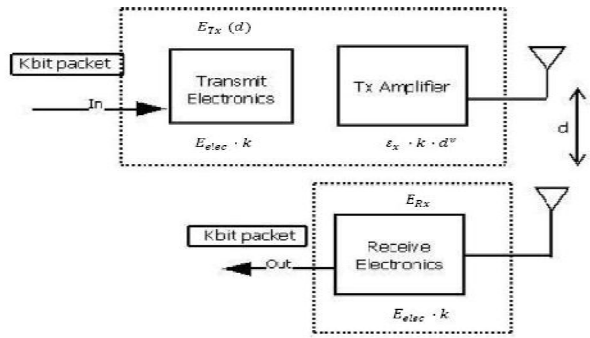

Figure 1: Network Model

4. FORMATION OF CLUSTERS

A distributed algorithm is used to form a cluster in this thesis. The main idea is for the nodes to elect themselves with respect to their energy levels autonomously. n is the total number of nodes in the network. The main goal is to minimize the communication cost and maximize the network resources in order to ensure concise data is sent to the base station. The threshold function of choosing cluster head is given as $T(n)$. An optimal number of clusters are ‘c’ in each round. Each node can become a cluster-head with probability P_{opt} and every node must become cluster head once every 1/ P_{opt} rounds. Means it has nP_{opt} clusters and cluster heads.

$$T(n) = \begin{cases} \frac{P_{opt}}{1-P_{opt}\left[r \bmod\left(\frac{1}{P_{opt}}\right)\right]}, & n \in G; \\ 0, & otherwise \end{cases} \quad (3)$$

G is the set of non-elected nodes in the past 1/ P_{opt} rounds. Each node will choose a number between 0 and 1, if this is lower than threshold, the node will become cluster head.

$$c_{opt} = \sqrt{\frac{n}{2\pi}} \frac{M}{d_{toBS}} \quad (4)$$

Nodes are distributed in an area of M ×M m^2. d_{toBS} is the distance of CHs to the BS.

5. ADVANCED SEP-E PROTOCOL (ASEP-E)

This section of the paper discusses the proposed solution as an extension to SEP-E protocol by considering four energy levels in two hierarchy settings which is the first improvement to SEP-E. The new enhanced protocol is referring to as ASEP-E (advanced SEP-E). The second improvement is that the modified scheme optimizes the stable region of the network system by further increasing the epoch to accommodate the additional energy level introduced in this work. In this new additional node called 'super-advanced nodes' are introduced into the system, to cater the multi-node diversity. The re-energization of the network system by deploying new nodes to replace the dead nodes can be very important for some specific applications such as continuous data retrieval process.

The 'super-advanced nodes' has the energy greater than advanced nodes. Mathematically, the energy can be described as $E_0 < E_{int} < E_{adv} < E_{sadv}$. As in SEP-E protocol the energy of the normal nodes is E_0, for intermediate nodes is $(1+\beta)\ E_0$, for advanced nodes is $(1+\alpha)\ E_0$. For the super advanced nodes the energy is $(1+\gamma)\ E_0$, where β, α and γ are the energy factor of the intermediate, advanced and super advanced nodes respectively. Figure 2 and 3 show the heterogeneous settings used.

The new heterogeneous network with four-tier node energy has no effect on the special density of the network. The probability remains P_{opt} remains the same. But the total energy of the network is increased from $nE_0\,(1 + m\alpha + x\beta)$ to $nE_0\,(1 + m\alpha + x\beta + q\gamma)$ by the introduction of super advanced nodes. Where n is the total number of nodes in the network, m is the proportion of advanced nodes to the total number of nodes n, x is the proportion of intermediate nodes and q is the proportion of super advanced nodes.

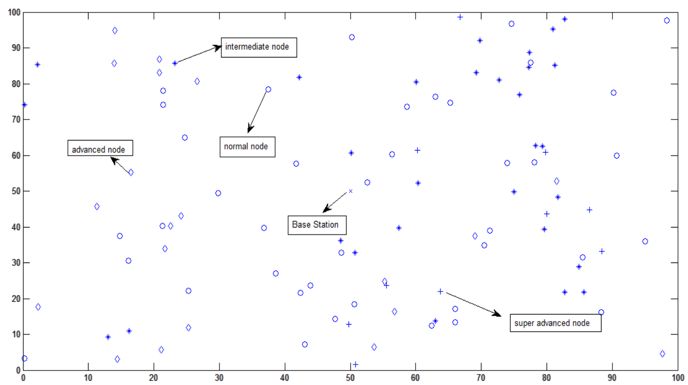

Figure 2: Wireless Sensor Network, this is the setting of the modified protocol showing different types of nodes

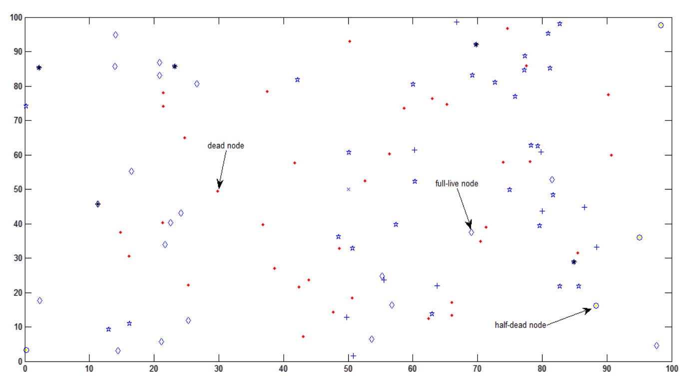

Figure 3: Wireless Sensor Network showing live nodes, half-dead nodes and dead nodes during sensing process

The following conditions must be satisfied.

1. The super advanced nodes must be CHs $(1+\gamma)$ times every $\frac{1}{P_{opt}}(1 + m\alpha + x\beta + q\gamma)$.
2. The advanced nodes must be CHs exactly $(1+\alpha)$ times every $\frac{1}{P_{opt}}(1 + m\alpha + x\beta + q\gamma)$.
3. The intermediate nodes must be CHs exactly $(1+\beta)$ times every $\frac{1}{P_{opt}}(1 + m\alpha + x\beta + q\gamma)$.
4. Every normal node must become CHs once every $\frac{1}{P_{opt}}(1+ m\alpha + x\beta + q\gamma)$.
5. The average number of cluster in the network should be nP_{opt}.

ASEP-E used an election probability based on the initial energy of each node to elect the cluster-heads by assigning a weight equal to the initial energy of each node divided by initial energy of normal nodes. The weighted probabilities for normal, intermediate, advanced and super-advanced nodes are chosen to reflect the extra energy introduced into the network system. The probabilities of becoming cluster heads for normal, intermediate, advanced and super advanced nodes respectively are given below:

$$P_{nrm} = P_{opt}\ /(1 + m\alpha + x\beta + q\gamma) \quad (5)$$

$$P_{int} = P_{opt}\ (1 + \beta)/(1 + m\alpha + x\beta + q\gamma) \quad (6)$$

$$P_{adv} = P_{opt}\ (1 + \alpha)/(1 + m\alpha + x\beta + q\gamma) \quad (7)$$

$$P_{sadv} = P_{opt}\ (1 + \gamma)/(1 + m\alpha + x\beta + q\gamma) \quad (8)$$

To guarantee that the sensor nodes must become cluster heads as described above, new thresholds must be defined for the election process. These are given below:

$$T(n_{nrm}) = \begin{cases} \frac{P_{nrm}}{1-P_{nrm}\left[r \bmod\left(\frac{1}{P_{nrm}}\right)\right]}, & n_{nrm} \in G'; \\ 0\ , & otherwise \end{cases} \quad (9)$$

G' is the set of normal nodes that has not become cluster head in the past $1/P_{nrm}$ round r. Similarly, for other types of nodes the threshold becomes

$$T(n_{int}) = \begin{cases} \frac{P_{int}}{1-P_{int}\left[r \bmod\left(\frac{1}{P_{int}}\right)\right]}, & n_{int} \in G''; \\ 0\ , & otherwise \end{cases} \quad (10)$$

G'' is the set of intermediate nodes that has not become cluster head in the past $1/P_{int}$ round r.

$$T(n_{adv}) = \begin{cases} \frac{P_{adv}}{1-P_{adv}\left[r \bmod\left(\frac{1}{P_{adv}}\right)\right]}, & n_{adv} \in G'''; \\ 0\ , & otherwise \end{cases} \quad (11)$$

G''' is the set of advanced nodes that has not become cluster head in the past $1/P_{adv}$ round r.

$$T(n_{sadv}) = \begin{cases} \frac{P_{sadv}}{1-P_{sadv}\left[r \bmod \left(\frac{1}{P_{sadv}}\right)\right]}, & n_{sadv} \in G''''; \\ 0 \quad , & otherwise \end{cases} \quad (12)$$

G'''' is the set of super advanced nodes that has not become cluster head in the past $1/P_{sadv}$ round r.

So, the average number of cluster heads per round will be:

$$n\,(1\text{-}m\text{-}x\text{-}q)P_{nrm} + nxP_{int} + nmP_{adv} + nqP_{sadv} = nP_{opt} \quad (13)$$

In summary, A-SEP-E protocol is designed to exploit four energy levels/nodes i.e. normal, intermediate, advanced and super advanced nodes in two level hierarchy settings to extend the lifetime of the clustered WSN.

6. RESULTS AND DISCUSSIONS

6.1 Simulation Settings

Assuming a 100 × 100 m^2 area consists of 100 sensor nodes scattered randomly. MATLAB is used to implement the simulation. Let 10%, 20% and 30% of the nodes be super-advanced, advanced and intermediate nodes respectively with additional energy levels: $\gamma = 6$, $\alpha = 3$ and $\beta = 1.5$ respectively. The new heterogeneous epoch becomes $\frac{1}{P_{opt}}(1 + m\alpha + x\beta + q\gamma)$. Since P_{opt}= 0.1 on average there should be 10 nodes becoming cluster heads per round. This means by the new heterogeneous epoch there should be, on average n (1-m-x-q) Pnrm= 1 normal node become cluster head per round.

Similarly, we should have nxP_{int} = 3 intermediate nodes becoming cluster heads per round, nmP_{adv} = 3 advanced nodes becoming cluster heads per round and nqP_{sadv}= 3 super advanced nodes becoming cluster heads per round. Other parameters used in the simulation are given in the Table 1.

Table 1: Parameter settings

Parameter	Values
E_{elec}	50nJ/bit
E_{DA}	50nJ/bit/message
E_0	0.5J
k	4000
P_{opt}	0.1
ϵ_{fs}	10pJ/bit/m^2
ϵ_{mp}	0.0013pJ/bit/m^4
N	100

6.2 Performance Metrics

To evaluate the performance of the clustering protocols, the following measures are used:

1. *Stability period*: is the time interval from the start of the network operation until the death of the first node. This is also referred as "stable region".

2. *Network lifetime*: is the time interval from the start of operation until the death of the last alive node.

3. *Number of nodes alive per round*: This instantaneous measure reflects the total number of nodes and that of each type that has not yet expended all of their energy.

6.3 Simulation Results

This section presents the results of the experiments comparing SEP, SEP-E and ASEP-E. The authors in the SEP discussed how SEP exploited the energy imbalance to extend the lifetime of the WSN. In SEP the stable region is extended compared with that of LEACH in two-node setting.
Here, SEP, SEP-E and new proposed protocol 'ASEP-E' are compared and stability of the proposed protocol is better.

The lifetime of the proposed protocol is also improved from SEP and SEP-E protocols.

The number of nodes alive per round when compared taking three cases of ASEP-E protocol is shown in Figure 4.
Case 1: q = 0.05, $\gamma = 3$, m=0.2, $\alpha = 2$, x = 0.25, $\beta = 1$,
Case 2: q = 0.05, $\gamma = 6$, m=0.1, $\alpha = 3$, x = 0.2, $\beta = 1.5$ and
Case 3: q = 0.1, $\gamma = 6$, m=0.2, $\alpha = 3$, x = 0.3, $\beta = 1.5$ in four-node heterogeneous setting.

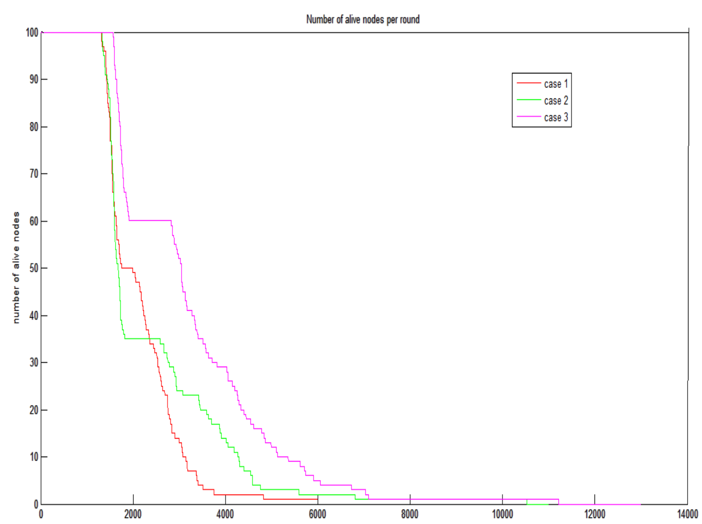

Figure 4: The performance of ASEP-E taking three different cases of heterogeneity

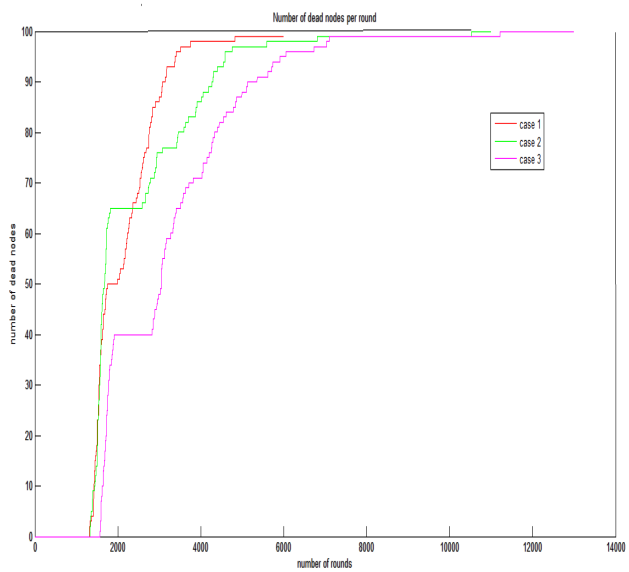

Figure 5: The performance of ASEP-E taking three different cases of heterogeneity

Network lifetime with three different cases is 6136, 10524 and 11209 rounds for case 1, case 2 and case3 respectively. So, there is improvement of 1.49, 2.3 and 1.5 times than SEP-E.

The number of dead nodes per round when compared taking three cases of ASEP-E protocol is shown in Figure 5. The stability period for case 1, case 2 and case 3 is 1311, 1325 and 1571 rounds respectively.

The total number of nodes alive per round is shown in Figure 6 and comparison is performed between SEP, SEP-E and ASEP-E protocols taking q = 0.1, $\gamma = 6$, m=0.2, $\alpha = 3$, x = 0.3 and $\beta = 1.5$ in four-node heterogeneous setting.

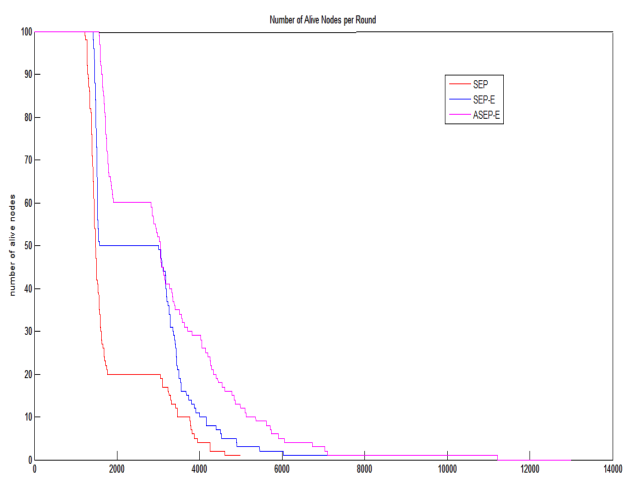

Figure 6: The performance of ASEP-E, SEP-E and SEP (q = 0.1, $\gamma = 6$, m=0.2, $\alpha = 3$, x = 0.3,$\beta = 1.5$) in the presence of energy heterogeneity

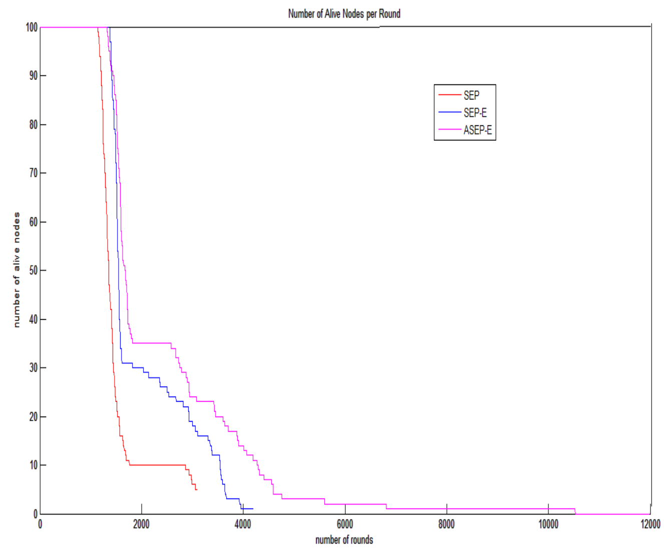

Figure 7: The performance of ASEP-E, SEP-E and SEP (q = 0.05, $\gamma = 6$, m=0.1, $\alpha = 3$, x = 0.2,$\beta = 1.5$) in the presence of energy heterogeneity

In Figure 7 the total number of alive nodes per round is shown and comparison is performed between SEP, SEP-E and ASEP-E protocols taking q = 0.05, $\gamma = 6$, m=0.1, $\alpha = 3$, x = 0.2 and $\beta = 1.5$ in four-node heterogeneous setting.

In Figure 8 the total number of alive nodes per round is shown and comparison is performed between SEP, SEP-E and ASEP-E protocols taking q = 0.05, $\gamma = 3$, m=0.2, $\alpha = 2$, x = 0.25 and $\beta = 1$ in four-node heterogeneous setting.

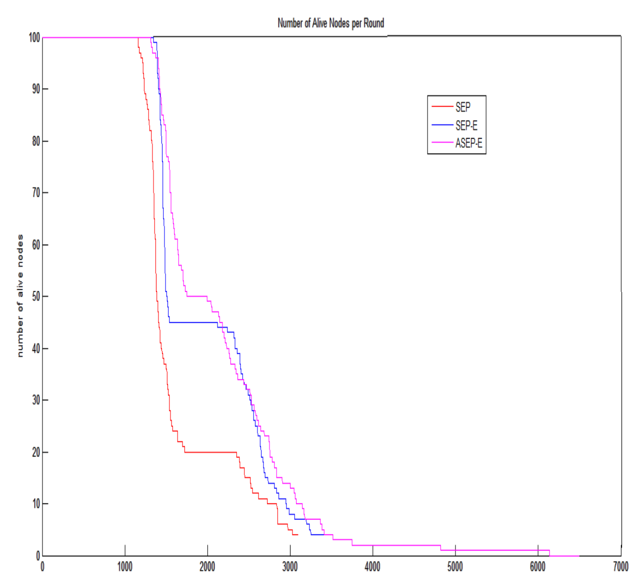

Figure 8: The performance of ASEP-E, SEP-E and SEP (q = 0.05, $\gamma = 3$, m=0.2, $\alpha = 2$, x = 0.25,$\beta = 1$) in the presence of energy heterogeneity

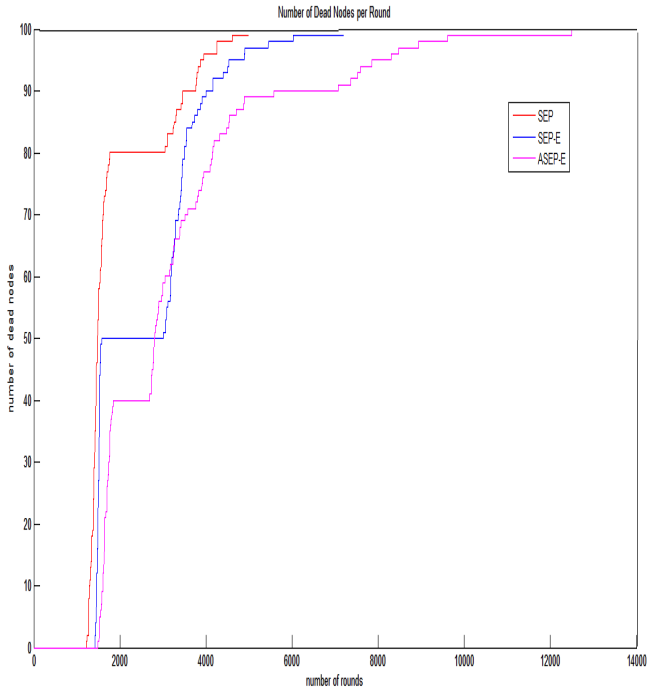

Figure 9: The number of dead nodes in ASEP-E, SEP-E and SEP ($q = 0.1$, $\gamma = 6$, $m=0.2$, $\alpha = 3$, $x = 0.3$, $\beta = 1.5$) in the presence of energy heterogeneity

In Figure 9, 10 and 11 the total number of dead nodes per round is shown and comparison is performed between SEP, SEP-E and ASEP-E protocols taking three different cases as discussed above in four-node heterogeneous setting.

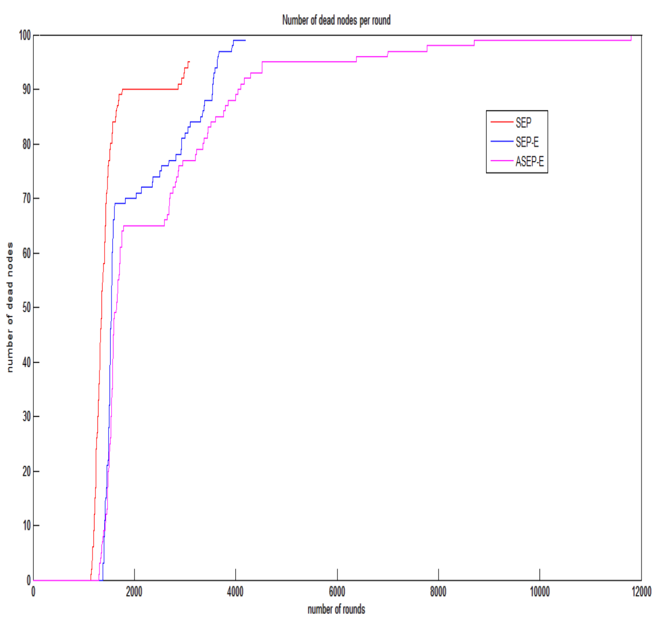

Figure 10: The number of dead nodes in ASEP-E, SEP-E and SEP ($q = 0.05$, $\gamma = 6$, $m=0.1$, $\alpha = 3$, $x = 0.2$, $\beta = 1.5$) in the presence of energy heterogeneity

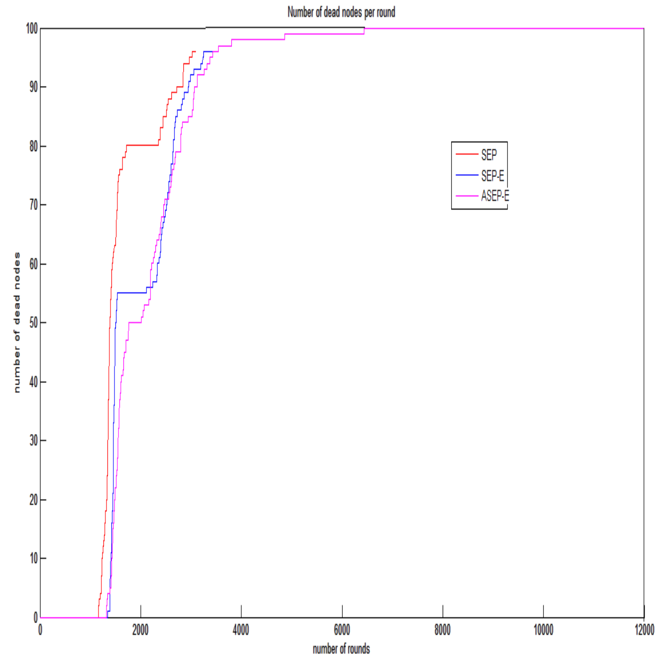

Figure 11: The number of dead nodes in ASEP-E, SEP-E and SEP ($q = 0.05$, $\gamma = 3$, $m=0.2$, $\alpha = 2$, $x = 0.25$, $\beta = 1$) in the presence of energy heterogeneity

Table 2 and 3 shows the improvement in ASEP-E protocol in comparison to SEP and SEP-E.

Table 2: Improvement in ASEP-E

Number of nodes that are dead	**SEP**	**SEP-E**	**ASEP-E**	**IMPROVEMET**
Round in which first node dead	1219	1425	1571	1.10 times
50% nodes are dead	1481	1581	3047	1.92 times
90% nodes are dead	3461	4007	5125	1.28 times
95% nodes are dead	3874	4332	5912	1.36 times

Table 3: Improvement in lifetime

LIFETIME				
CASES	SEP	SEP-E	ASEP-E	IMPROVEMENT
1	5758	7213	11209	1.94, 1.55 times
2	6643	4427	10524	1.58, 2.38 times
3	4011	4111	6136	1.52, 1.49 times

7. CONCLUSION AND FUTURE SCOPE

We proposed 'ASEP-E', an adaptive clustering protocol that is self-organizing in two-level hierarchy using four types of nodes: super advanced nodes, advanced nodes, intermediate nodes and normal nodes in heterogeneous setting. Another source of the energy heterogeneity could be the original network settings. Thus, in SEP and SEP-E the death of nodes starts much earlier than ASEP-E. So, there is a significant improvement in the performance of the network with ASEP-E protocol in terms of increase in number of rounds that leads to enhance the network lifetime that is 1.94 times higher than SEP and 1.55 times higher than SEP-E protocol. Number of packets received at the BS over the number of rounds show that packet delivery by ASEP-E is better than SEP-E and SEP.

This work can be extended to multi-hierarchy and multi-level system where communication can be by multi-hop or dual-hop instead of a single-hop. Here, different nodes can perform various functions such as filtering and other signal processing tasks. By considering more than two levels of hierarchy i.e. by forming chain of nodes data can be sent through this chain to minimize their energy consumption. Techniques can be applied to balance the number of nodes in the clusters.

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