Heterogeneous Routing Protocols in Wireless Sensor Network: A Survey

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Abstract: In a heterogeneous wireless sensor network, higher energy nodes can become cluster heads more times than the nodes with low energies. This means that creation of cluster heads and assigning tasks to them can greatly contribute to energy efficiency which results in increase in stability and network lifetime. Recent years have seen a tremendous growth in wireless sensor networks due to reduction in manufacturing costs and improvement in hardware manufacturing. Wireless Sensor Networks are now widely used in various fields like industrial monitoring, habitat monitoring, environment monitoring, surveillance etc. As these networks are energy limited, researchers are working on these networks in making them more energy efficient. A lot of energy efficient heterogeneous routing protocols have been proposed in recent years to increase the stability and overall lifetime of the network and this paper provides a review on these protocols.

Keywords: SEP, DEEC, DDEEC, EDEEC, EDDEEC, BEENISH

1. INTRODUCTION

Wireless Sensor network (WSN) is a group of spatially distributed autonomous devices (called Sensor Nodes) using sensors to monitor physical or environmental conditions such as temperature, vibration, motion, pressure, etc connected wirelessly with each other and to a common processing center called 'Sink or Base Station'. According to the requirement of network application, hundreds and thousands of sensors are deployed in wireless sensor networks. Wireless Sensor Network is one of the evolving technologies [1]. Different types of sensors in the sensor nodes measures the required parameters and then transmits these parameters to the Base Station directly or indirectly, where they are further used for different applications. WSN can be used for both military as well as civil applications. Military can use sensor networks for guarding borders from infiltration, smuggling, etc by using motion sensors. Nowadays, global warming is the main problem due to which glaciers are melting and as a result flooding takes place. So, the sensors can be deployed along the bank of rivers which can provide real time information about the level of the water. This information can then be used for disaster management. So, there are many applications of the WSN's like environmental monitoring, industrial sensing, battlefield awareness, temperature sensing, etc. So, in this way, these sensor nodes were, are and will be very helpful in the coming years.

Generally, Wireless Sensor Network is composed of large number of sensors with low processing power and energy consumption for monitoring a certain environment. Routing is the main challenge faced by wireless sensor network. Routing is complex in WSN due to dynamic nature, limited battery life, computational overhead, no conventional addressing scheme, self organization and limited range of sensor nodes. As sensor nodes has limited battery life and this battery cannot be deployed due to the area of deployment. So the main challenge in running a WSN is to use this energy very efficiently. Also due to the energy constraint, the direct communication between the sensor nodes and the sink is not feasible. So, one effective way is to divide the network into several clusters, each electing one node as it cluster head. The cluster head collects the data from nodes in the cluster which will be then aggregated and transmitted to the sink. Thus, only some nodes are required to transmit data over a long distance and the rest of the nodes will need to do only short distance transmission. Then, more energy is saved and overall network lifetime can thus be increased. All the heterogeneous protocols are designed based on the clustering structure where cluster heads are elected periodically based on the different criteria. A lot of research has been done and is still going on how to increase the lifetime of the network by using battery energy efficiently.

In a wireless sensor network, all the senor nodes can either have a same energies or different. The network with each node having same energy is called homogeneous wireless sensor network while the network with some nodes having energies different from others are called heterogeneous wireless sensor network. Heterogeneity can be introduced initially in the network or it can occur when some nodes in the homogeneous network are re-energised which results in difference in the energies of the sensor nodes. Also, it is very difficult to manufacture senor nodes with same energies, due to which heterogeneity remains always there. The heterogeneity can be of various levels like two level heterogeneity, three level heterogeneity, etc. Two level heterogeneity means that some nodes in a network are at one energy level while the remaining are at another.

The first work that questioned the behavior of clustering protocols in the presence of heterogeneity in clustered wireless sensor networks was W. R. Heinzelman [2]. In his work, Heinzelman analyzed a method to elect cluster heads according to the energy left in each node. The drawback of this method is that this decision was made per round and assumed that the total energy left in the network was known. The assumption of global knowledge of the energy left in the whole network makes this method difficult to implement. Even a centralized approach of this method would be very complicated and very slow, as the feedback should be reliably delivered to each sensor in every round.

In [3], Duarte-Melo and Liu examined the performance and energy consumption of wireless sensor networks, in a field where there are two types of sensors. They consider nodes that are fewer but more powerful that belong to an overlay. All the other nodes have to report to these overlay nodes, and the overlay nodes aggregate the data and send it to the sink. The drawback of this method is that there is no dynamic election of the cluster heads among the two types of nodes, and as a result nodes that are far away from the powerful nodes will die first. The authors estimate the optimal percentage of powerful nodes in the field, but this result is very difficult to use when heterogeneity is a result of operation of the sensor network and not a choice of optimal setting.

In [4], Mhatre and Rosenberg presented a cost-based comparative study of homogeneous and heterogeneous clustered wireless sensor networks. They proposed a method to estimate the optimal distribution among different types of sensors, but again this result is hard to use if the heterogeneity is due to the operation of the network. They also studied the case of multi-hop routing within each cluster (called M-LEACH). Again the drawback of the method is that only powerful nodes can become cluster heads (even though not all powerful nodes are used in each round.) Furthermore, M-LEACH is valid under many assumptions and only when the population of the nodes is very large.

Other power-aware routing schemes [5], [6] assume that the exact position of each node is known a priori (e.g. each node is equipped with GPS, which increases the cost per node), and that initially, nodes are homogeneous. Such strong assumptions and especially centralized solutions [6], may not be applicable for low-cost, large-scale networks.

All the heterogeneous routing protocols uses cluster head algorithm and this algorithm is broken into rounds. A round means when all the alive nodes send's their data once to the sink. At each round, node decides whether to become a cluster head based on the threshold calculated by the suggested percentage of the cluster heads for the network (determined a priori) and the number of times the node has been a cluster head so far. This decision is made by the nodes by choosing random number between 0 and 1. If the number is less than a threshold T(s), the node becomes a cluster-head for the current round. The threshold is set as:

$$T(s) = \begin{cases} \frac{p}{1-p\left(r \bmod \frac{1}{p}\right)} & \text{if } s_i \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Where p is the probability of the node 's_i' and this value changes for each protocol for each node, r is the current round number and G is the set of nodes that have not been cluster heads in the last $1/p_{opt}$ rounds. Using this threshold, each node will be a cluster head, just once at some point within $1/p_{opt}$ rounds.

The performance parameters used to compare the protocols has been defined below as:

- Stability Period: It is defined as the number of rounds from the start of the network operation to the round when first node of the network dies.
- Network Lifetime: It is defined as the number of rounds from the start of the operation to the round when last node in the network dies.
- Throughput: It is defined as the total amount of data received by the sink.

2. HETEROGENEOUS ROUTING PROTOCOLS

Heterogeneous routing protocols are described as:

2.1 SEP (Selection Election Protocol)

Georgios Smaagdakis, Ibrahim Matta and Azer Bestavros [7] proposed SEP (Stable Election Protocol) in which there two types of nodes called normal nodes and advance nodes with advance nodes having (1+a) more energy than the normal nodes. Every sensor node in a heterogeneous two-level hierarchical network independently elects itself as a cluster head based on its initial energy relative to that of other nodes. The probabilities for nodes to be cluster head is given by equation (2):

$$p=\begin{cases} \frac{P_{opt}}{1+am} & \text{for normal nodes;} \\ \frac{P_{opt}\,(1+a)}{1+am} & \text{for advance nodes;} \end{cases} \qquad (2)$$

Unlike [2], SEP does not require any global knowledge of energy at every election round. Unlike [3], [4], SEP is dynamic in that it does not assume any prior distribution of the different levels of energy in the sensor nodes. Furthermore, the analysis of SEP is not only asymptotic, i.e. the analysis applies equally well to small sized networks. Finally SEP is scalable as it does not require any knowledge of the exact position of each node in the field.

2.2 DEEC (Distributed Energy-Efficient Clustering)

Li Qing, Qingxin Zhu and Mingwen Wang [8] proposed this protocol which also works at two levels of energy as in case of SEP protocol and has better stability period than SEP protocol. In DEEC, the cluster heads are elected by a 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 will have more chances to be the cluster heads than the nodes with low energy. So, the advance nodes have more chances to be cluster heads than the normal nodes. The probabilities of normal, advance and super nodes are given by equation (3):

$$p=\begin{cases} \frac{P_{opt}\,E_i(r)}{(1+am)\,\bar{E}(r)} & \text{for normal nodes;} \\ \frac{P_{opt}\,(1+a)\,E_i(r)}{(1+am)\,\bar{E}(r)} & \text{for advance nodes;} \end{cases} \qquad (3)$$

where $E_i(r)$ is the residual energy of the node 's_i' at round 'r', $\bar{E}(r)$ is the average energy at round 'r' of the network which is determined a priori before the deployment of the nodes in the network.

Finally, the simulation results shows that DEEC achieves longer lifetime and more effective messages than other previous protocols.

2.3 DDEEC (Developed Distributed Energy-Efficient Clustering)

Brahim Elbhiri, Saadane Rachid, Sanaa El fkihi and Driss Aboutajdine [9] proposed this protocol which was 30% better than SEP and 15% better than DEEC in terms of Network lifetime and Stability period. This protocol also works at two levels of energy and overcomes the drawbacks of the DEEC protocol. DEEC is based on clustering, when the cluster heads are elected by a probability based on the ratio between residual energy of each node and the average energy of the network. The round number of the rotating epoch for each node is different according to its initial and residual energy. DEEC adapt the rotating epoch of each node to its energy. The nodes with high initial and residual energy will have more chances to be cluster heads than the nodes with low energy. Thus DEEC can prolong the network lifetime, especially the stability period. This choice penalizes always the advanced nodes, specially when their residual energy deplete and become in the range of the normal nodes. In this situation, the advanced nodes die quickly than the others. The DDEEC, thus balances the cluster head selection over all network nodes following their residual energy. So, the advanced nodes are likely to be cluster heads during initial period but as the energy of the advance nodes depletes and become comparable with the normal nodes, the advance nodes will have the cluster head election probability like the normal nodes. The probabilities are given by equation (4):

$$p=\begin{cases} \frac{P_{opt}\,E_i(r)}{(1+am)\,\bar{E}(r)} & \text{for normal nodes if } E_i(r) > Th_{rev}; \\ \frac{P_{opt}(1+a)E_i(r)}{(1+am)\bar{E}(r)} & \text{for advance nodes if } E_i(r) > Th_{rev}; \\ c\,\frac{P_{opt}\,(1+a)E_i(r)}{(1+am)\bar{E}(r)} & \text{for normal, advance nodes if } E_i(r) \le Th_{rev} \end{cases} \qquad (4)$$

where $Th_{rev}=bE_o$ and $b\in(0,1)$. If $b = 0$, we'll have the traditional DEEC. But in a reality and durante simulation, all advanced nodes cannot be even a cluster heads. The same case for normal nodes, it's probable that some of them will be a cluster heads. Then, this last value of b is not exact. So, through lot of simulations with a random topology, we have to try to find the nearest value of b which gives the best results. The value of c is a real positive variable which control directly the clusters head number. On one hand, if c is higher, the number of cluster heads will increase. Then, the network scheme will be like a direct communication because all nodes will be a cluster head and transmit directly here information to the base station, in this case the network performances will increase. On the other hand, if c = 0, the probability to be a cluster heads will be equal to zero for all nodes. So, they go to transmit directly their measurement to the base station, thus, they die quickly. To solve this, compromise and find the correct value of c which gives an important results through simulations.

So, by removing this penalizing effect, the DDEEC protocol outperforms the DEEC protocol.

2.4 EDEEC (Enhanced Distributed Energy Efficient Clustering)

Parul Saini and Ajay K. Sharma [10] proposed EDEEC protocol which works on the same principle of DEEC but adds a third type of node called super node which has (1+b) times more energy than normal node. Advance nodes have (1+a) times more energy than normal nodes. Due to this third node, the heterogeneity of the network increases from two to three. Traditionally as per previous protocols, in this protocol too, cluster head selection uses the same threshold technique and the advance and normal nodes have same probabilities. Difference is just that this protocol has a probability formula for super nodes too.

$$p=\begin{cases}\frac{p_{opt}\,E_i(r)}{1+m(a+m_o b)\bar{E}(r)} & \text{for normal nodes;}\\ \frac{p_{opt}\,(1+a)\,E_i(r)}{1+m(a+m_o b)\bar{E}(r)} & \text{for advanced nodes;}\\ \frac{p_{opt}\,(1+b)\,E_i(r)}{1+m(a+m_o b)\bar{E}(r)} & \text{for Super nodes;}\end{cases} \quad (5)$$

The simulations show that this protocol is better than SEP, which is also extended to three levels but based on its own principle, in terms of network lifetime and stability period.

2.5 EDDEEC (Enhanced Developed Distributed Energy Efficient Clustering)

N. Javaid, T. N. Qureshi, A.H. Khan, A. Iqbal, E. Akhtar and M. Ishfaq [11] proposed this protocol which also works at three levels of heterogeneity and overcomes the drawbacks of EDEEC protocol. In EDEEC protocol, the super nodes have more energy than the advance nodes which have more energy than the normal nodes. The probability of the super, advance and normal nodes to be cluster heads shown in above equation clearly shows that super nodes have high probability to be cluster head than the advance nodes which have more probability than normal nodes. So, after becoming cluster heads again and again, after some rounds, the energy of super nodes will become equal to that of advance nodes because cluster heads consumes more energy than the other nodes in the cluster. At this time, as the energies of the super and advance nodes becomes equal, but due to higher probability, the super nodes will again become cluster heads. Due to this, the super nodes will die fast which will reduce the lifetime of the network. This effect is called penalizing effect as in the DDEEC. So, to overcome this, the probability formulas are changed. All the nodes will use its respective probability formula until they reach a threshold energy level, $T_{absolute}$. When the energy of the nodes reaches $T_{absolute}$ or below, then all the nodes will use a common probability formula as given below;

If $E_i(r) > T_{absolute}$, then

$$p=\begin{cases}\frac{p_{opt}\,E_i(r)}{1+m(a+m_o b)\bar{E}(r)} & \text{for normal nodes;}\\ \frac{p_{opt}\,(1+a)\,E_i(r)}{1+m(a+m_o b)\bar{E}(r)} & \text{for advanced nodes;}\\ \frac{p_{opt}\,(1+b)\,E_i(r)}{1+m(a+m_o b)\bar{E}(r)} & \text{for Super nodes;}\end{cases} \quad (6)$$

If $E_i(r) \leq T_{absolute}$, then

$$p= c\,\frac{p_{opt}\,(1+b)\,E_i(r)}{1+m(a+m_o b)\bar{E}(r)} \text{ for all nodes} \quad (7)$$

And $T_{absolute}=zE_o$

Where $z \in (0,1)$. If z=0, then we have traditional EDEEC. In reality, advanced and super nodes may have not been a cluster head in rounds r, it is probable that some of them become cluster head and same is the case with the normal nodes. So, exact value of z is not sure. However, through numerous simulations using random topologies, the closest value of z is estimated by varying it for best result based on first dead node in the network. The value of c is a real positive variable which control directly the clusters head number. On one hand, if c is higher, the number of cluster heads will increase. Then, the network scheme will be like a direct communication because all nodes will be a cluster head and transmit directly here information to the base station, in this case the network performances will increase. On the other hand, if c = 0, the probability to be a cluster heads will be equal to zero for all nodes. So, they go to transmit directly their measurement to the base station, thus, they die quickly. That we won't certainly to avoid. To solve this, compromise and find the correct value of c which gives an important results through simulations.

Simulations show that this protocol is more efficient than the all previous protocols in terms of stability period as well as network lifetime.

2.6 BEENISH (Balanced Energy Efficient Network Integrated Super Heterogeneous) Protocol

N. Javaid, T. N. Qureshi, A.H. Khan, A. Iqbal, E. Akhtar and M. Ishfaq [12] proposed the first ever protocol for four levels of heterogeneity in the wireless sensor network. The fourth type of node introduced in this protocol is called ultra-super node which has (1+u) times more energy than normal nodes. This protocol proved that with the increase in heterogeneity, the stability period increases which is a very important parameter for a reliable information. BEENISH uses same concept for cluster head selection as in previous protocols with the difference only in addition of probability for ultra super nodes. The probabilities of ultra-super, super, advance and normal nodes to be cluster heads is given below:

$$P(i) = \begin{cases} \frac{Popt*Ei}{(1+m(a+m0(-a+b+m1(-b+u)))*Ea} & for\ norm\ nodes\ if\ Ei > Tab \\ \frac{Popt*Ei*(1+a)}{1+m(a+m0(-a+b+m1(-b+u)))*Ea} & for\ adv\ nodes\ if\ E(i) > Tab \\ \frac{Popt*Ei*(1+b)}{1+m(a+m0(-a+b+m1(-b+u)))*Ea} & for\ sup\ nodes\ if\ E(i) > Tab \\ \frac{Popt*Ei*(1+u)}{1+m(a+m0(-a+b+m1(-b+u)))*Ea} & for\ ult\ nodes\ if\ E(i) > Tab \\ \frac{c*Popt*Ei*(1+u)}{1+m(a+m0(-a+b+m1(-b+u)))*Ea} & for\ all\ nodes\ if\ E(i) \le Tab \end{cases} \quad (8)$$

Simulations show that BEEISH is the most efficient protocols as compared to DEEC, DDEEC, EDEEC in terms of stability period, network lifetime and throughput.

3. COMPARISON OF VARIOUS HETEROGENEOUS ROUTING PROTOCOLS

Table1: Comparison of heterogeneous routing protocols

Protocols	Number of levels of Heterogeneity	Stability Period (rounds)	Network lifetime (rounds)	Drawback
SEP	2	935	Low	Global Status required
DEEC	2	1103	Low	Penalizing Effect
DDEEC	2	1367	Middle	Only for 2 level
EDEEC	3	1421	High	Penalizing Effect
EDDEEC	3	1717	High	For 3 level
BEENISH	4	1661	High	Penalizing Effect

4. CONCLUSION

In this paper, we discussed various heterogeneous routing protocols like SEP, DEEC, DDEEC, EDEEC, EDDEEC and BEENISH for wireless sensor network. The main concern of this survey is to examine the stability period, network lifetime, throughput and compare the performances of all heterogeneous protocols. It is being found that level of stability period has been certainly enhanced with the increase of heterogeneous levels. Where SEP being the first one to introduce the heterogeneity in the network, But has the downside that it requires global knowledge of the network. DEEC worked on the residual energy concept and DDEEC worked on avoiding the penalization of advanced nodes. EDEEC worked on three level heterogeneity and gave much stability period. EDDEEC introduced the concept of threshold for the first time at three level heterogeneity to avoid penalization of advanced nodes. BEENISH is the first protocol to work on the four level heterogeneity to enhance the stability period. However it lacks in avoiding the penalizing effect on advance nodes.

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