Comparative Analysis of Energy Efficient Protocols for Prolonged Life of Wireless Sensor Network

Gagandeep Singh, H. P. Singh and Anurag Sharma

Abstract The efficiency of Wireless Sensor Networks (WSNs) depends on the routing protocols used, since routing protocol provide the best possible data transmission route from sensor nodes to sink to save energy of nodes in the network. The clustering schemes enhance the network lifetime, raise the scalability and reduce the energy consumption of the sensor network. The work in this paper presents the comparative analysis of the energy efficient routing protocols for WSN such as SEP, TSEP and DSEP. The optimized routing protocol has been proposed on the basis of the network life time, stability and cluster head selection for efficient working of the sensor networks.

Keywords Wireless sensor networks · Clustering · SEP · TSEP · DSEP

1 Introduction

Wireless sensor networks are composed of many homogeneous or heterogeneous sensor nodes with restricted resources. A single sensor node is the combination of three components: processor, sensor and wireless communication device (trans-receiver) as presented in Fig. 1. These sensor nodes spread throughout it to observe, collect, and transmit data. The sensors are economical, simple and their power supply is irreplaceable. Early study on wireless sensor networks generally focused on technologies based on the homogeneous wireless sensor network in

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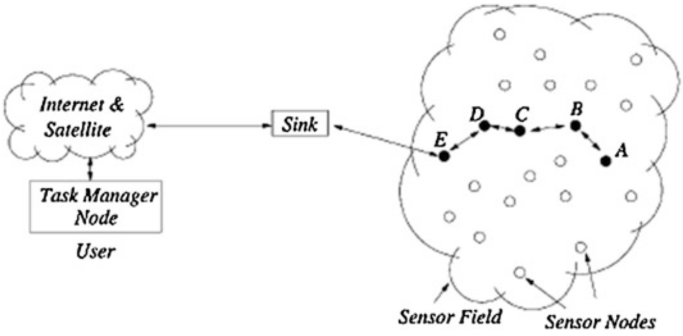
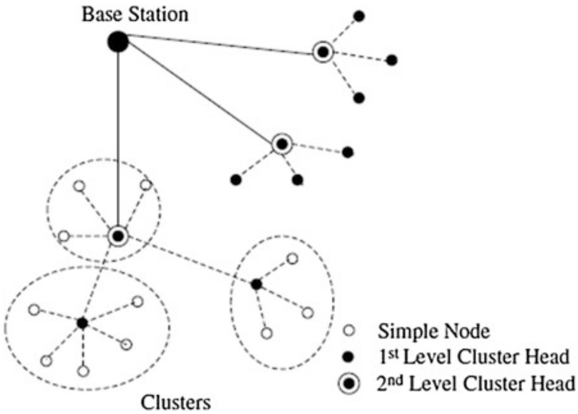


Fig. 1 Wireless sensor network [12]

Fig. 2 Nodes communicate to base station through cluster heads



which each node have same energy. Nevertheless, now a days heterogeneous wireless sensor networks are becoming more and more popular. The heterogeneous nodes can extend network lifetime and improve network reliability without extensively increasing the cost [1, 2]. A classic heterogeneous wireless sensor networks consists of a large number of normal nodes and a few heterogeneous nodes. The normal node is inexpensive and source-constrained whose major tasks are to sense and issue data report. The heterogeneous node, which provides data fusion, filtering and transport, is more costly and more proficient [3]. In a hierarchical topology, nodes are organized into number of clusters according to specific requirements or metrics and perform different tasks in WSNs. Clustering in WSNs contains grouping nodes into clusters and electing a cluster head. The member nodes of a cluster can communicate with their cluster head directly. The cluster head is able to forward the combined data to the central base station with the help of other cluster heads [4].

The nodes having higher energy can act as cluster head which carry out the task of data processing and information transmission, whereas nodes having low energy are normal nodes which carry out the task of information sensing as shown in Fig. 2.

In the previous few years, a comparatively large number of hierarchical clustering routing protocols have been developed for WSNs. In this paper, we broadly review and significantly discuss the most vital hierarchical clustering routing algorithms that have been used for WSNs. The related work has been presented in the next section and the brief description the energy efficient routing protocols has been presented in the Sect. 3. The Sect. 4 presents the comparative results and discussion. The last section concludes the work and presents the future work.

2 Related Work

LEACH is the first clustering based routing protocol for WSNs. This protocol relates arbitrary rotation of cluster head to equally distribute energy load between sensor nodes to improve stability period and network lifetime [5]. LEACH is basically designed for homogeneous networks in which the nodes having equal initial energy.

PEGASIS protocol [6] uses greedy algorithm to organize the sensor nodes into a sequence chain, thus every node transmits and receives the data from the nearby neighbor. But if the node fails, discovering of new route becomes complicated as each node has a set route before the transmission towards the base station.

Stable Election Protocol (SEP) [7] uses weighted election probabilities for every node to become cluster-head according to their respective energy. The cluster head selection is randomly selected and distributed based on the fraction of energy of every node. SEP considered two types of nodes, normal nodes and advanced nodes respectively and also uses two levels of heterogeneity. This protocol is basically designed to raise time interval of first dead node.

TSEP [8] is a reactive routing protocol in which nodes have three different levels of energies. Cluster heads selection is threshold based which causes increase in stability period and network life.

A Deterministic-SEP (D-SEP) [9] is proposed, for selecting cluster heads in a circulated fashion in two-, three-, and multi-level hierarchical wireless sensor networks. This protocol uses improved SEP algorithm for wireless sensor networks in the presence of energy heterogeneity. By using a heterogeneous three-level node setting in a clustering algorithmic approach, nodes select themselves as cluster heads based on their energy levels, retaining uniformly distributed energy among all sensor nodes.

3 Routing Protocols for WSN

In this section, we analyze three standard WSN clustering routing algorithms in detail and present a broad and vital survey of important clustering routing protocols for WSNs. For the purpose of this study, we use similar radio communication and consumption model as reported in [7].

3.1 SEP

SEP protocol [7] is based on two levels of heterogeneity. A fraction '*m*' of total '*n*' nodes is given with an extra energy factor '*A*', which is known as, advanced nodes. Therefore, probability of normal node and advanced node to become cluster head is $p_{nrm} = p/1 + mA$ and $p_{adv} = p * (1 + A)/1 + mA$ respectively, where '*p*' is the best possible probability of every node to become cluster head. Cluster heads selection in SEP is completed arbitrarily on the basis of probability of every type of node as in LEACH. Nodes sense data and transmit it to associated cluster head which transmit it to base station. By increasing 'p_{adv}' or '*m*', we can further improve our system. Thus, SEP results in better stability period and network life due to advance nodes however two-level heterogeneity also caused enlarged throughput [8].

3.2 TSEP

TSEP (Threshold sensitive Stable Election Protocol) is based on three levels of heterogeneity and has a reactive routing protocol [8]. Advance nodes having energy greater than all other nodes; intermediate nodes have energy in between normal and advance nodes whereas the remaining nodes are normal nodes. Intermediate nodes can be elected with '*x*', a part of nodes which are intermediate nodes and by using the relation that energy of normal nodes is 'μ' times additional than that used for the normal nodes. In the case of SEP energy considered for normal nodes is E_o, for advance nodes it is $E_{adv} = E_o(1 + A)$ and energy for intermediate nodes can be calculated as $E_{in} = E_o(1 + \mu)$, where $\mu = A/2$. As a result, the total Energy of all the nodes will become $n{*}E_o(1 + m{*}A + x{*}n)$ where, '*n*' is number of nodes, '*m*' is fraction of advanced nodes to entire number of nodes '*n*' having energy greater than remaining of nodes and '*x*' is fraction of intermediate nodes. The best possible probability of nodes, which are separated on the basis of energy, to be selected as a cluster head can be computed by using following formulas:

$$P_{nrm} = p{*}/(1 + m{*}A + x{*}n) \quad (1)$$

$$P_{int} = p{*}(1 + \mu)/(1 + m{*}A + x{*}n) \quad (2)$$

$$P_{adv} = p{*}(1 + A)/(1 + m{*}A + x{*}n) \quad (3)$$

Thus, to ensure that cluster head selection is made in the similar method as we have assumed, we have taken an additional factor into consideration, which is threshold level. Every node produces randomly a number inclusive of 0 and 1, when produced value is less than threshold then this node turns into cluster head [5].

For every this types of node, there are different formulas for the computation of threshold depending upon their probabilities, which are shown below:

$$T_{nrm} = p_{nrm}/[1- p_{nrm}(r^{*}mod\ 1/p_{nrm})], \quad if\ n_{nrm}\ €\ G' \tag{4}$$

$$T_{int} = p_{int}/[1-p_{int}(r^{*}mod\ 1/p_{int})], \quad if\ n_{int}\ €\ G'' \tag{5}$$

$$T_{adv} = p_{adv}/[1-p_{adv}(r^{*}mod\ 1/p_{adv})], \quad if\ n_{adv}\ €\ G''' \tag{6}$$

Here G', G'' and G''' are the set of normal nodes, intermediate nodes and advanced nodes that has not turn out to be cluster heads in the past respectively.

3.3 DSEP

The threshold value is modified in DSEP by using the residual energy and set as [9]:

$$T_{(Si)} = [p_i/1 - (p_i * (r\ mod\ 1/p_i))] * [E_{residual} + (r_s div\ 1/p_i) * (1 - E_{residual})] \tag{7}$$

Now 'r_s' is the number of successive rounds in which a node has not been cluster-head. If 'r_s' reaches the value of $1/p_i$, the threshold $T(S_i)$ is reset to the value. Therefore, the possibility of node 'n' to become cluster head improves because of a high threshold. Moreover, 'r_s' is reset to '0' if a node becomes cluster head. So, we ensure that data is reached to the base station as long as nodes are alive.

In weighed election probability of three- level heterogeneity nodes known as normal, advanced and intermediate nodes are measured based on partial difference in their initial energy level. At this time the reference value of 'p_i' is different for nodes. The probabilities of normal, advanced and intermediate nodes are [9–11]:

$$P_i = \{ P_{nrm}, P_{int}, P_{adv} \} \tag{8}$$

where

$$P_{nrm} = p^{*}E_{residual}/(1 + m^{*}A + x^{*}n) * E_{average} \tag{9}$$

$$P_{int} = p^{*}(1 + \mu) * E_{residual}/(1 + m^{*}A + x^{*}n) * E_{average} \tag{10}$$

$$P_{adv} = p^{*}(1 + A) * E_{residual}/(1 + m^{*}A + x^{*}n) * E_{average} \tag{11}$$

Threshold value for cluster head selection is considered for normal, advanced, intermediate nodes by putting above values in Eq. (7) or else it is zero. G', G'' and G''' is the set of normal and advanced nodes.

4 Results and Discussion

In our present work, a comparative analysis of DSEP with SEP and TSEP protocols on the basis of network lifetime, stability period and throughput is achieved after creating a 100 m × 100 m region of 100 sensor nodes spread randomly. The sink or base station is located at the center point (50 × 50). The packet size that the nodes send to their cluster heads as well as the combined packet size that a cluster head sends to the sink is set to 4,000 bits. The parameters used in the simulation are mentioned below in Table 1.

4.1 Stability Period

Stability period is defined as the time interval from the start of network operation until the death of the first sensor node. Figure 3 illustrates the number of dead nodes for $m = 0.4$, $A = 1$, $\mu = 0.5$, $x = 0.2$ over 5,000 rounds. It is observed that for SEP with two types of nodes having different initial energy, the first sensor node dies at the round of around 863 whereas due to availability of more nodes with extra energy in TSEP, the first sensor node dies at the round of around 1,184 which is more than SEP. It is observed that in DSEP, stability period is greater than SEP and TSEP protocols as the first node dies at around 1,417.

Further, for $m = 0.6$, $A = 1.5$, $\mu = 0.75$, $x = 0.3$ over 6,000 rounds, it is observed from the Fig. 4, that for the SEP the first sensor node dies at the round of around 1,132 whereas the first sensor node dies for TSEP is at around 1,420 which is again more than SEP. And the first sensor node for DSEP is around 1,483 which is greater than SEP and TSEP. So, it shows that in DSEP, stability period is greater than TSEP and SEP.

4.2 Network Lifetime

Network lifetime is defined as the time interval from the start of operation (of the sensor network) until the death of the last alive node. Figure 5 illustrates the lifetime of the sensor network for $m = 0.4$, $A = 1$, $\mu = 0.5$, $x = 0.2$ over 5,000 rounds. We can observe that for the SEP protocol the last sensor node dies at 2,565 and for TSEP protocol, the last sensor node dies 3,905 rounds whereas for DSEP the last sensor node still alive over 5,000 rounds. It shows that the lifetime of network for DSEP is more than TSEP and SEP.

Further, for $m = 0.6$, $A = 1.5$, $\mu = 0.75$, $x = 0.3$ over 6,000 rounds, it is observed from the Fig. 6, that for the SEP the last sensor node dies at the round of around 3,120 and the last sensor node dies for TSEP is at around 3,732 which is

Table 1 Simulation parameters

Parameters	Value
Network field	(100, 100)
Number of nodes	100
E_o (Initial energy of nodes)	0.5 J
Message size	4,000 bits
E_{elec}	50 nJ/bit
E_{amp}	0.0013 pJ/bit/m^4
E_{fs}	10 nJ/bit/m^2
E_{DA}	5 nJ/bit/signal
D_o (Threshold distance)	70 m

Fig. 3 Number of dead nodes for m = 0.4, A = 1, μ = 0.5, x = 0.2

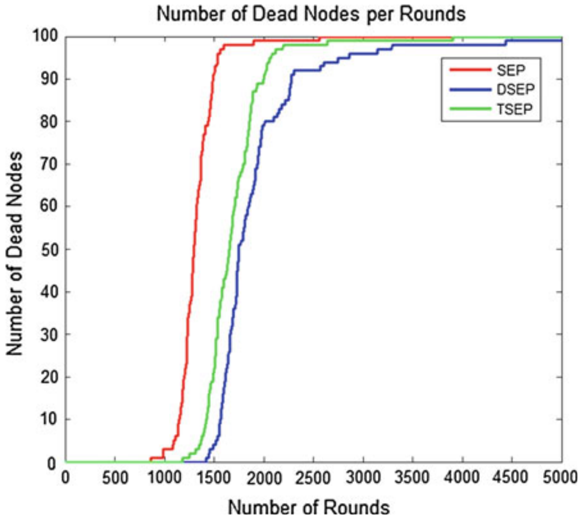
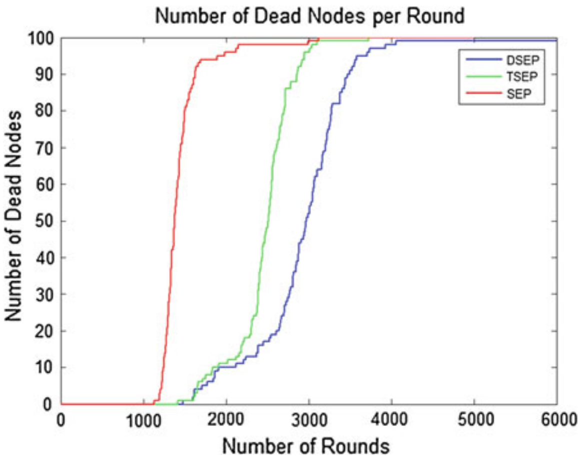


Fig. 4 Number of dead nodes for m = 0.6, A = 1.5, μ = 0.75, x = 0.3



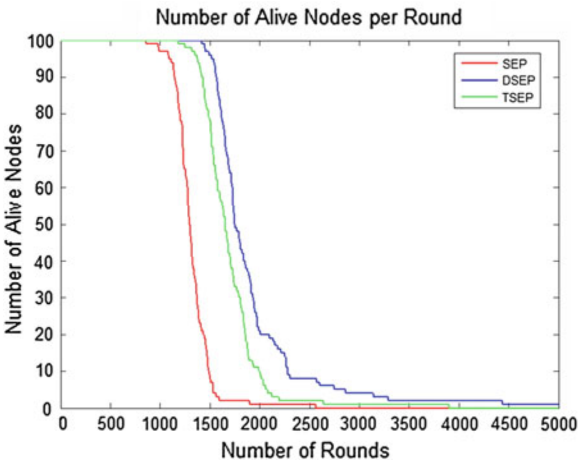


Fig. 5 Lifetime of the sensor network for m = 0.4, A = 1, μ = 0.5, x = 0.2

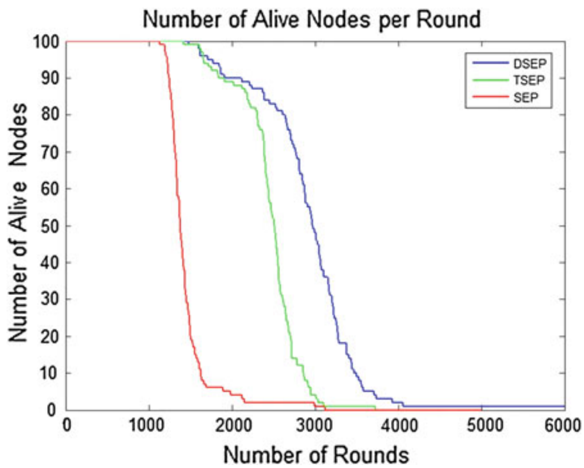


Fig. 6 Lifetime of the sensor network for m = 0.6, A = 1.5, μ = 0.75, x = 0.3

again more than SEP whereas for DSEP the last sensor node still alive over 5,000 rounds. It is again observed that the lifetime of network for DSEP is more than TSEP and SEP.

4.3 Throughput of the Network

Figures 7 and 8 illustrate the throughput of the sensor network in terms of the cluster heads alive to send the received packets to the base station or sink. We can observe that for the existing SEP protocol having two types of sensor nodes, the throughput is stable enough up to around 1,104 rounds for the values *m = 0.4,*

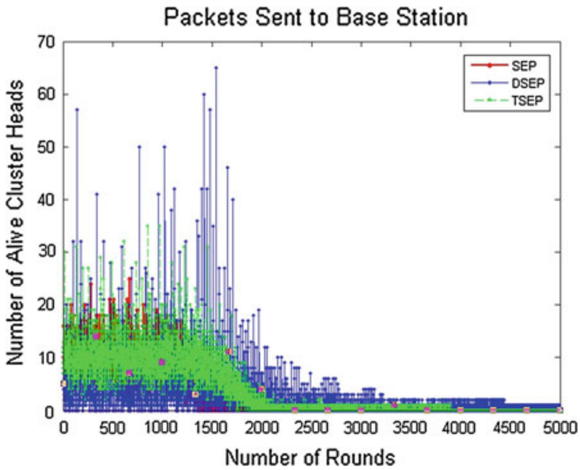


Fig. 7 Throughput of the sensor network for m = 0.4, A = 1, μ = 0.5, x = 0.2

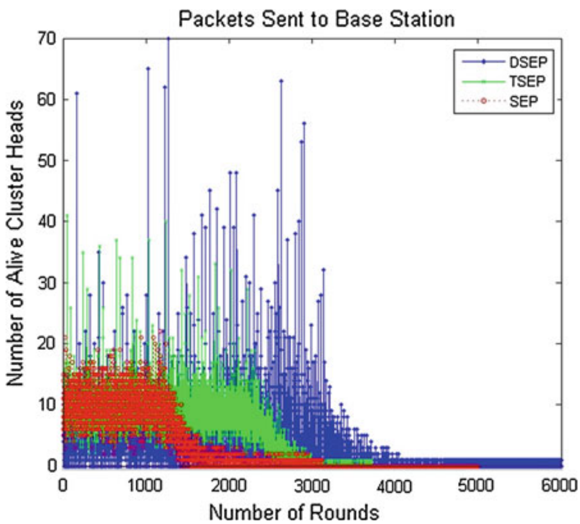


Fig. 8 Throughput of the sensor network for m = 0.6, A = 1.5, μ = 0.75, x = 0.3

$A = 1$ and up to 1,456 rounds for the values $m = 0.6$, $A = 1.5$. Moreover, for the TSEP protocol having three types of sensor nodes, the throughput is stable enough up to 1,783 rounds for the values $m = 0.4$, $A = 1$, $\mu = 0.5$, $x = 0.2$ and up to 2,550 for the values $m = 0.6$, $A = 1.5$, $\mu = 0.75$, $x = 0.3$. But with the increasing number of rounds the network throughput decreases whereas for the DSEP protocol, the throughput is stable enough up to 2,100 rounds for the values $m = 0.4$, $A = 1$, $\mu = 0.5$, $x = 0.2$ and up to 3,300 for the values $m = 0.6$, $A = 1.5$, $\mu = 0.75$, $x = 0.3$.

5 Conclusion

SEP is based on weighted election probabilities of every node to become cluster head according to the remaining energy and TSEP is reactive routing protocol in which nodes have three different levels of energies. Cluster heads choice is threshold based, due to three levels of heterogeneity. A comparative analysis of DSEP, which is based on the weighted probabilities to get the threshold for normal, super and advanced nodes points us to elect the cluster head in every round, provides a longer network lifetime, stability period and higher throughput as compared to the existing SEP and TSEP protocols. For the future scope the present work can be extended as an advanced DSEP to deal with clustered wireless sensor networks with more than three levels of hierarchy and more than three types of nodes.

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