

Improvement in Stable Election Protocol for Heterogeneous Wireless Sensor Network

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Abstract: With the advancement in technology and networking scenario the application of wireless sensor networks (WSNs) have increased rapidly and they exploit large amount of minute sensor nodes to perform complex functions like different types of computation and signal processing with their limited power source which is available from the battery embedded in themselves. Hence, in designing any wireless sensor network (WSN) it is necessary to consider the network lifetime as the main factor and develop an energy efficient protocol to enhance the network lifespan. Cluster-based routing protocol is considered to be the most appropriate energy efficient protocol in WSNs. In this paper, an extended stable election protocol (DT-SEP) is discussed with an additional factor in the different election probabilities of cluster head election for different energy levels of nodes in heterogeneous network. The simulation results show that the proposed protocol improves the network lifetime to some extent achieves lesser energy consumption of nodes and enhanced stability period in comparison to SEP-E.

Keywords: Stability, Sink node, Cluster Head (CH), Lifetime, Average energy

1. Introduction

Wireless sensor network (WSN) has captivated a great attention of many researchers in the recent years due to its high demand in different applications in our day-to-day life. Some of these applications can be mentioned as object tracking and surveillance, weather forecasting, climate and enemy monitoring, health care systems, precision agriculture, etc. WSN comprises of many minute sensing devices called as sensor nodes (SNs) or simply nodes to perform the activities like observing or monitoring any environmental parameter specified for the network. These nodes get their power supply from battery which is not possible to replace it once they are deployed in the network. Therefore, optimising the energy efficiency of the network and enhancing the network lifetime are the main challenges faced by wireless sensor networks (WSNs). This can be obtained by reducing the energy consumption of the nodes with proper routing protocol. Cluster-based protocol is considered to be one of the most energy efficient protocol in WSNs¹. Number of cluster-based protocols have been proposed. Among them, low energy adaptive clustering hierarchy (LEACH) is the most notable energy efficient protocol for homogeneous network². However, in this paper the lifetime extension will be analysed for heterogeneous network with three different energy levels of nodes based on enhanced stable election protocol³ and the performance comparison is evaluated for different initial energy levels with proposed protocol called as DT-SEP.

In cluster-based algorithms, the whole network is grouped into clusters of some nodes and corresponding cluster heads are selected for the clusters. These cluster heads are responsible for gathering the data from the participant nodes in the cluster and forward the accumulated data to the base station or sink node. This data transmission can either be single-hop or multi-hop transmission according to the requirement of the application. This approach reduces the energy dissipation to a large extent and performs far better than minimum transmission energy (MTE) and direct transmission². An improved SEP is proposed in this paper with the inclusion of distance value of nodes from the base station in the network to deal with the problem of fast energy consumption of network nodes and this inclusion of additional factor provides a great improvement in network lifetime and in some other network performance parameters also which will be discussing in the result section.

2. Related Works

Clustering algorithms can be used in both homogeneous and heterogeneous network. In homogeneous network all the nodes are equipped with same initial energy but in heterogeneous network the nodes are of different initial energy level. Power efficient gathering in information systems (PEGASIS)⁴, hybrid energy efficient distributed clustering approach (HEED)⁵ and LEACH are some of the popular clustering protocols in homogeneous network and stable election probability (SEP)⁶, energy efficient cluster schemes in wireless sensor networks (EECS)⁷ and distributed energy efficient schemes for heterogeneous wireless sensor networks (DEEC)⁸ are some of the popular heterogeneous networks. Although homogeneous networks are more common in practical applications it is more suitable to study the characteristic features of WSN in heterogeneous condition since the homogeneous network becomes heterogeneous after performing operations for some time due to some internal processing and non-uniform consumption of energy by nodes.

PEGASIS is a chain based protocol where a single node takes the leadership role and will transmit the sensed data to the base station in turn wise manner. All the nodes will be given the chance of becoming leader node in the network. HEED is a cluster-based protocol where cluster heads are selected periodically considering the residual energy of nodes as the primary parameter for cluster head selection and the number of nodes surrounding the candidate node (i.e. node degree) as the secondary parameter metrics for cluster head election. In SEP the authors proposed a protocol where they consider two different energy levels of nodes, i.e. normal nodes and advanced nodes and this is the first protocol where the heterogeneity condition of nodes is considered. The communication in this protocol is single-hop communication and the nodes are assumed to be immobile with uniform distribution of nodes in the network. The authors in DEEC protocol selects the cluster heads based on the residual energy of nodes and average energy of the network. Majority of these protocols are proposed to improve the network lifetime. In advanced SEP-E the authors consider four levels of energy of nodes namely normal, intermediate, advanced and super advanced nodes to increase the network lifetime⁹. An enhanced threshold sensitive stable election protocol is proposed for heterogeneous wireless sensor network where the authors consider ratio of residual energy of nodes and the product of average energy of network with optimum cluster heads in the threshold condition of the various energy levels of nodes in the network¹⁰. This approach shows a great improvement

in the network lifetime. A distance based residual energy efficient stable election protocol for WSNs is proposed to improve the network lifetime and to optimise energy utilisation in the network¹¹. Figure 1 represents a simple clustering process in cluster-based protocol.

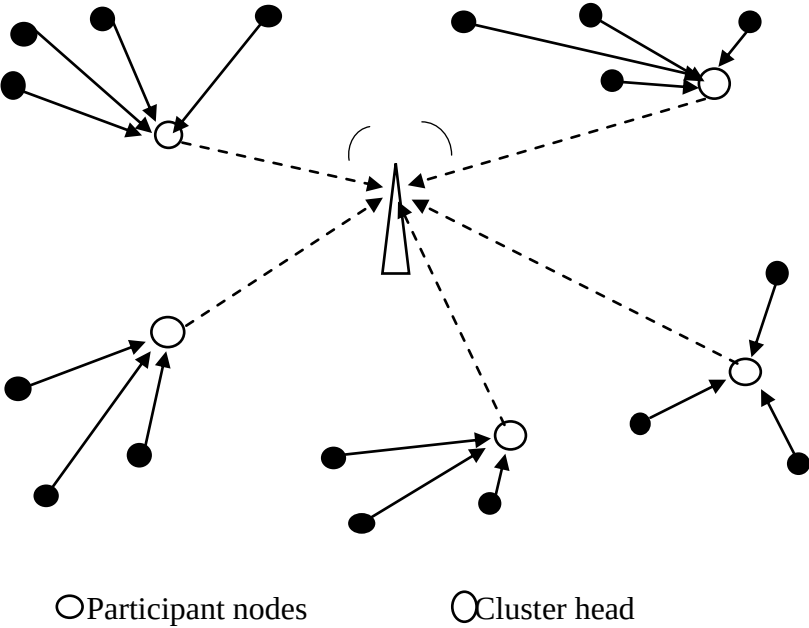


Figure 1. Clustering process in cluster-based algorithm

3. Heterogeneous network

In this analysis, n number of nodes is uniformly distributed in the network of area $100 \times 100 m^2$ as shown in Figure 3. Theses nodes are assumed to have data always to transmit to the base station and are stationary if once deployed in the network. From the concept of advancement in SEP three different energy levels of nodes are taken namely advanced nodes (+) which have the highest energy in the network, intermediate nodes () with lower energy than advanced nodes but higher to ordinary (or normal) nodes and ordinary nodes () which constitute the minimum energy among the nodes deployed in the observation area^{1,9,11}. Advanced nodes possess a times higher energy than the ordinary nodes and intermediate nodes acquire b times higher energy than the ordinary nodes.

The initial energy of normal nodes is assumed to be E_0 , m_a is the proportion of advanced nodes to the total number of nodes and m_i is the proportion of intermediate nodes in the network.

3.1 SEP-E: In SEP-E¹ protocol the cluster heads are elected based on the corresponding election probabilities and the associated threshold value of different energy levels of nodes which is given in (2.4). Every epoch and the election probabilities of cluster heads correspond to the initial energy level of nodes and are given as follows:

$$(3.1) \quad p_{nn} = \frac{p_1}{1 + m_a.a + m_i.b} \quad \text{for normal nodes}$$

$$(3.2) \quad p_i = \left[\frac{p_1(1+b)}{1 + m_a.a + m_i.b} \right] \quad \text{for intermediate nodes}$$

$$(3.3) \quad p_a = \left[\frac{p_1(1+a)}{1 + m_a.a + m_i.b} \right] \quad \text{for advanced nodes}$$

The threshold condition of this protocol is given as:

$$(3.4) \quad T(n_n) = \begin{cases} \frac{p_n}{1 - p_n * (r \bmod 1/p_n)}, & n \in G_n \\ 0, & \text{otherwise,} \end{cases}$$

where n_n indicates nodes in the network and G_n represents the nodes that are appropriate to be cluster heads and acted as participant nodes in the recent rounds, p_1 is the optimum probability of cluster heads and r is the number of present rounds and

$$(3.5) \quad p_n = \begin{cases} p_{nn} & \text{if the node is normal node} \\ p_i & \text{if the node is intermediate nodes} \\ p_a & \text{if the node is advanced nodes} \end{cases}$$

3.2 Proposed approach DT-SEP: This proposed protocol utilises the simple radio energy dissipation model² as shown in Figure 2.

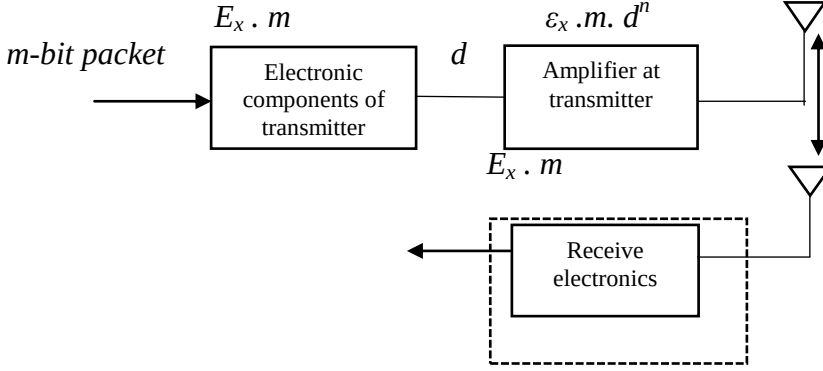


Figure 2. Radio energy model ($\epsilon_x n$ represents the corresponding path model and path loss exponent)

For proper communication, the energy dissipated by the radio in transmitting m -bit data over distance d is given as follows:

$$(3.6) \quad E_t = mE_x + m\epsilon_f d^2, \quad d < d_0,$$

$$(3.7) \quad E_t = mE_x + m\epsilon_{mp} d^4, \quad d \geq d_0,$$

where E_t is the transmitter energy needed for transmission of m bits over d distance, m is number of bits that have to be sent, ϵ_f and ϵ_{mp} is the necessary energy of an amplifier required for amplification of a single bit for free space propagation and multipath fading propagation model respectively, E_x is the energy dissipation by electronic components for transmitting or receiving a bit, d is the separation range between transmitter and receiver. If the node is located at a distance less than crossover distance d_0 then it follows free space propagation else it follows multipath or two ray model propagation.

The crossover distance d_0 value² is given by

$$(3.7) \quad d_0 = \sqrt{\frac{\epsilon_f}{\epsilon_{mp}}}$$

The energy dissipation at the receiver to receive m -bit packet is given by

$$(3.8) \quad E_r = mE_x.$$

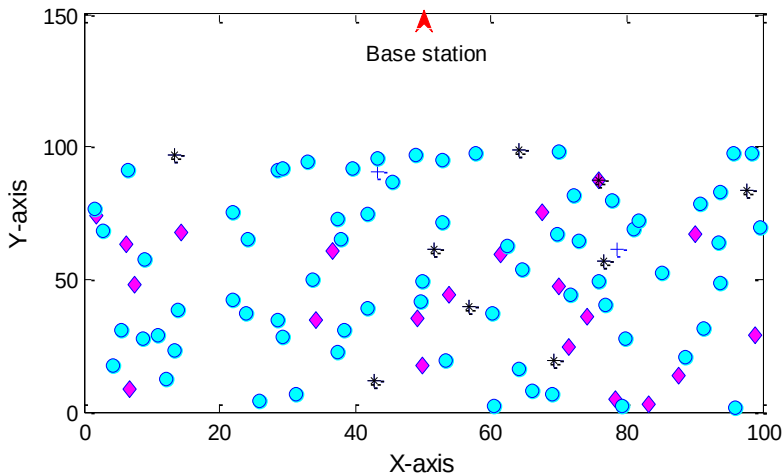


Figure 3. Nodes in heterogeneous network (DT-SEP at random rounds 20, * indicates cluster heads)

As stated by the radio propagation model, the amplifier and the transmitter energy required for data transmission is directly proportional to the distance of nodes from the base station. For closer nodes the energy required by cluster heads for data transmission is lesser in comparison to far away nodes from the base station even though the numbers of participant nodes are considered to be similar. The energy lay out for computation process and signal processing by the sensor nodes is of negligible amount with respect to the large amount of energy required for direct data transmission to the base station. From this concept, it can be asserted that the cluster heads which are at distant location from the base station consumed much more energy than the nearby nodes. Hence, after some rounds of clustering process there will be huge non uniformity in the energy consumption of nodes in the network. This leads to early death of far away nodes and faster energy depletion than the closer nodes and further results in unequal observation and collection of data in the network (reduces reliability).

In this proposed approach, base station will broadcast ‘hello’ message to the whole network so that every node will hear this broadcast message. The

base station will transmit this message with enough signal strength as it has no constraint of power source and every node will estimate its distance from the base station by using the signal strength of the broadcasted message received by it. This algorithm allows the nodes located far away from the base station and which have low energy in the network to be elected as cluster heads less often than the nearer nodes with more energy in the network. With this estimation of distance, new election probabilities for nodes with different energy levels are introduced so that the algorithm will favour the nodes to take the cluster head role not only on the basis of initial energy of nodes but also depending on the distance of nodes from the base station. The new election probabilities can be written as:

$$(3.9) \quad p_{nn} = \left[\frac{p_1}{(1 + m_a \cdot a + m_i \cdot b)} \right] * \left[\delta^* \left\{ \frac{1 - d(i)}{(d_{\min} + d_{\max})} \right\} \right],$$

$$(3.10) \quad p_i = \left[\frac{p_1(1+b)}{(1 + m_a \cdot a + m_i \cdot b)} \right] * \left[\delta^* \left\{ \frac{1 - d(i)}{(d_{\min} + d_{\max})} \right\} \right],$$

$$(3.11) \quad p_a = \left[\frac{p_1(1+a)}{(1 + m_a \cdot a + m_i \cdot b)} \right] * \left[\delta^* \left\{ \frac{1 - d(i)}{(d_{\min} + d_{\max})} \right\} \right],$$

where $d(i)$ is the distance of node from the base station and $d_{\min}$, $d_{\max}$ represents the minimum and maximum distance of nodes from the base station respectively and δ is a constant that can be in the range $[0.5, 1]$. In this study, the constant is taken to be 0.8 for appropriate cluster heads selection. From the various simulation readings that have been carried out it is found that this value is more suitable for this algorithm than the other values. This constant is added so that the election probability does not take a very low value when the distance of nodes increases. With these new election probabilities, the cluster heads will be selected based on the threshold condition given by (3.5).

The data transmission process follows similar steps as in enhanced SEP^{1,6}. After cluster heads election, the chosen cluster heads will advertise themselves as head nodes with their IDs and other remaining nodes will choose the nearest head nodes based on the received signal strength. The

member nodes will be acknowledged by the cluster heads with time slots for sending their sensed data using TDMA (time division multiple access) scheme. Accordingly, the participant nodes in each cluster will send their sensed data to the corresponding cluster head in their allocated time slots assigned by the cluster heads. The head nodes will forward the data after accumulating the data collected from the member nodes. The energy expenditure by cluster head is given by:

$$E_{ch} = mE_{elec}k + mE_{AGR}(k+1) + mE_{elec} + m\varepsilon_x d_{sink}t,$$

where E_{elec} is the energy expenditure by electronic components per bit, E_{AGR} is the energy required for aggregation per bit, k is the number of cluster participant nodes, ε_x is the amplifier energy, d_{sink} is the distance of nodes from base station, t represents the power raise to distance base on the propagation model

4. Results

The performance evaluation is carried out using MATLAB simulation. A wireless sensor network is considered with $n=100$ nodes deployed in the observation dimension of 100×100 metres. The base station is located at (50,150) from the centre of the network. The transmission is considered to be interference free and has no packet collision during the transmission. The electronic components energy per bit $E_{elec} = E_x$ is taken to be 5 nJ/bit, εfs is 10 pJ/bit/m², ε_{mp} is 0.0013 pJ/bit/m⁴, E_{AGR} is 5 nJ/bit/packet. The simulation is performed for two different initial energy of normal nodes 0.5 J and 0.25 J. The packet size is taken to be 4000 bits and the optimum probability of cluster heads selection p_1 to be 0.1. The value of m_a , m_i , a and b are taken to be 0.1, 0.2, 3 and 2 respectively. Some of the main terms are defined as follows:

Stability period: The time duration from the initial operation of the network till the death of first node.

Lifetime of network: The condition when all nodes in the network died or when there is no communication between the base station or user end and the deployed network nodes or when the reliability (accuracy) of data decreases to a reasonable level.

FND (first node dead): The death of first node in the network.

Table 1. Number of rounds with percentage of dead nodes

Enhanced SEP (SEP-E)			DT-SEP		
% of dead nodes	rounds		% of dead nodes	rounds	
	$E_o = 0.5\text{ J}$	$E_o = 0.25\text{ J}$		$E_o = 0.5\text{ J}$	$E_o = 0.25\text{ J}$
20	1208	572	20	1302	647
40	1339	670	40	1394	741
60	1489	757	60	1503	825
80	2009	1024	80	2624	1239
90	2745	1515	90	3246	1721

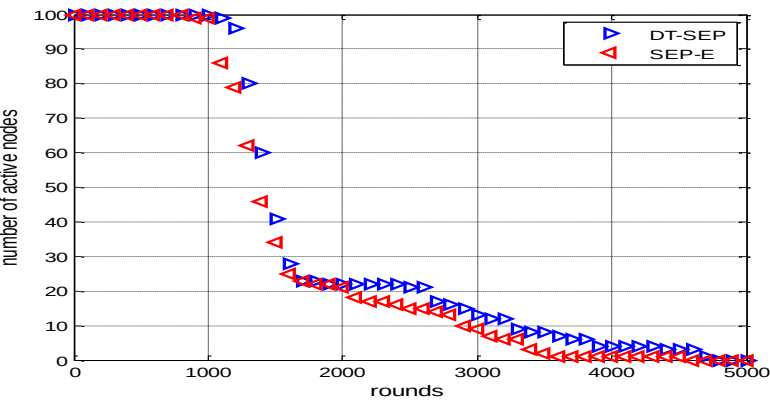


Figure 4. Active nodes vs rounds with $E_o = 0.5\text{ J}$

From Table 1 it can be observed that the rate of reducing alive nodes is slower in proposed protocol (DT-SEP) than the heterogeneous SEP-E protocol indicating that the network lifetime improves in the proposed approach. The improvement is obtained for different initial energy level of nodes (E_o). In this study the network lifetime is considered as the time duration upto which only 10% of active nodes are available in the network as the reliability decreases with decrease in active nodes. Figure 4 and Figure 5 show that DT-SEP achieves a visible improvement in lifespan of the network as a whole due to the selection of appropriate nodes as cluster heads. This improvement indicates that the inclusion of nodes' distance in the election probabilities provides enhancement in the lifetime of network irrespective of initial energy of heterogeneous network.

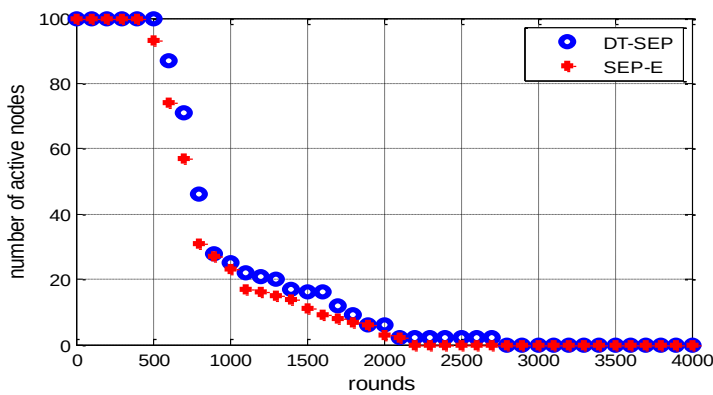


Figure 5. Active nodes vs rounds with $E_0 = 0.25\text{ J}$

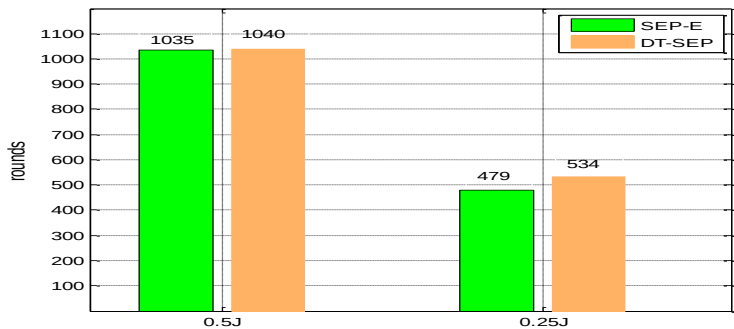


Figure 6. Stability period vs rounds for different E_0 values

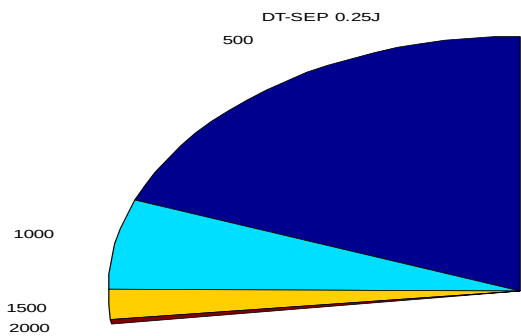


Figure 7. Pie chart of average residual nodes' energy in random rounds 500, 1000, 1500 and 2000 rounds

Figure 6 shows the stability period of proposed approach and SEP-E protocol for heterogeneous network. It indicates that there is significant

improvement in DT-SEP comparing to SEP-E which proves that the first node dead occurs at significantly later period in DT-SEP than SEP-E. This is due to the control process of forging far away nodes to become cluster heads less frequently than the nearer nodes. Figure 7 and Figure 8 indicates pie chart of average residual energy of nodes in the network with initial energy of 0.25 J for normal nodes for DT-SEP and SEP-E respectively. It can be seen from these two figures that the proposed protocol DT-SEP has more average residual energy in random rounds.

5. Conclusion and Future work

This paper proposed a protocol DT-SEP for heterogeneous network which is energy aware and distance based clustering algorithm for enhancing the network lifetime. DT-SEP allows the nodes to elect themselves as cluster heads depending on their initial energy levels and distance of nodes from the base station thereby allowing the closer nodes to become cluster heads more often than the other nodes and save the far away nodes from fast degradation of their energy levels. The results show that the proposed approach provides better stability, better residual energy and enhanced network lifetime than SEP-E. In future, the proposed protocol can be implemented in mobile heterogeneous network and its performance for different initial energy levels, network parameters like latency, reliability, etc can be analysed.

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