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A Study on Election Based Clustering Protocols in Heterogeneous Wireless Sensor Networks

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Abstract

A wireless sensor network (WSN) is a wireless network that consists of independent self-directed devices that may be spatially distributed which use physical sensors to monitor physical or environmental conditions. A WSN may have thousands of sensor nodes which may have numerous technical electronic components which include radio, a microcontroller, a battery, sensors and sensor interfaces. In this article the performance analysis of clustering protocols in heterogeneous wireless sensor networks are done for Stable Election Protocol (SEP) and Threshold-Sensitive Stable Election Protocol (TSEP). WSN is an emerging technology that helps in monitoring the physical parameters in various aspects in today's world in different environments. Reducing the energy consumed and increasing the lifetime of the network become the most significant objectives of the routing protocols due to the energy. constraints of the WSNs. An optimum technique that can be used to prolong the lifetime of any sensor network and decrease the energy consumption is Clustering. The study shows that the two prominent energy efficient clustering protocols for heterogeneous wireless sensor networks is compared with different parameters like throughput, number of Alive nodes and residual energy with the help of software MATLAB and to find the best clustering protocol amongst the two with respect to the lifetime of the network.

Key Words: Wireless Sensor Networks, Clustering, Stable Election protocol, Threshold-Sensitive Stable Election Protocol.

INTRODUCTION

Wireless sensor network (WSN) is a highly developing technology in today's world. They have the capability to quickly capture process and transmit data with optimum high resolution to the base station. WSN is comprised of several sensor nodes that have a very low capacity for storage and very limited battery life [1]. The network may die because of the energy consumed which might be used for computation and transmission of data. It is not easy and feasible to substitute these batteries as the WSNs are deployed in isolated areas [2]. A WSN node may have several technical electronic components which include radio, battery, microcontroller, analog circuits, sensor and interfaces. In WSN radio technology, there are important trade-offs between the parameters like battery life, data rates, security, energy efficiency, etc.

To prolong the battery life, a WSN node wakes up periodically and transmits data by switching the radio on and then switching it back off to save the energy [3]. WSN radio technology proficiently transmits signals and allows the system to sleep when it is not transmitting and hence attains minimum power use. The wireless sensor networks have very wide range of applications. Wireless sensor network are emerging in various fields like environmental monitoring, mining, surveillance system, medical monitoring [4]. In any WSN, several numbers of nodes are deployed in a certain area. Hence, the concept of grouping of the sensor nodes is brought into picture and this concept is called "clustering". Clustering has many advantages that include useful consumption of energy, dropping the number of nodes taking part in transmission, scalability for large number of nodes, etc.

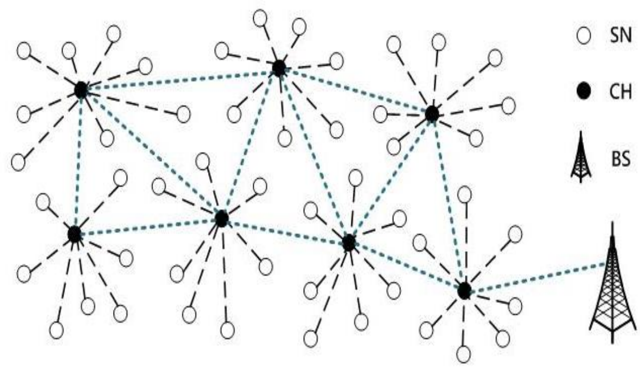

Figure 1: Clustering in WSN.

Clustering is a technique that balances the data load on the sensor network and also reduces the network's energy dissipation. Hence communication between the nodes and the base station is achieved by clustering [5]. Depending on the geographical distances, clusters are formed and apparently a cluster head is elected by considering the energy levels and a random probability that defines a node to become the cluster head. The cluster head changes in each round and one node is not elected as a cluster head more than once. The packets from the normal nodes are sent to the cluster heads. The cluster heads aggregates the data received from various nodes and then directs it to the base station. As, clustering gives an optimum solution in the reduction of energy by a network, a plenty of clustering protocols have been proposed till date. The clustering protocols may be homogeneous or may be heterogeneous [6]. And heterogeneous protocols are always proven to be more efficient than homogeneous ones. In this paper, simulation of two significant heterogeneous protocols Stable Election Protocol (SEP) and Threshold-Sensitive Stable Election Protocol (TSEP) protocols is done using MATLAB, analysed and compared.

RELATED WORK

The impact of heterogeneity of nodes in wireless sensor networks w.r.t. energy is studied. Within the network, a number of the nodes become cluster heads [1]-[5]. The cluster heads merge the information received from their cluster members, aggregate them and transmit it to the sink. It's assumed that a share of the population of sensor nodes is supplied with further energy resources. Also, it's assumed that the sensors area unit is randomly yet uniformly distributed. The coordinates of the sink and also the dimensions of the sensor field area unit are known. It was shown that the behaviour of such sensor networks becomes awfully unstable once the primary node dies. Classical agglomeration protocols assume that each one the nodes area unit will be equipped with a similar quantity of energy and as a result. They're unable to take full advantage of the presence of heterogeneousness of the nodes. In one such planned agglomeration protocols, a heterogeneous-aware protocol it is given as, to prolong the quantity within the stability period that is critical for several applications. SEP relies on weighted election possibilities of every node to become the cluster head consistent with the remaining energy in each node. Thus, one will say that the sensitivity of such SEP protocol to heterogeneousness parameters capturing energy imbalance within the network. It was found that SEP yields longer stability region for higher values of additional energy brought by a lot of powerful nodes [7]. One of the papers focuses on raising the network life of 3 stages based TSEP heterogeneous protocol of WSNs victimizing the [5] stage heterogeneousness level and conjointly by victimizing the onerous and soft threshold. The residue of the energies of the sensing element nodes have to get the optimum cluster heads [8]. It does not necessitate any worldwide knowledge of energy at any time through the length of WSNs. The comparison among TSEP and projected protocol has conjointly been done based mostly upon packets communicated, energy consumption and network life time [9]. The comparisons have shown that the projected technique outperforms over the TSEP. Also, attributable to 5 level heterogeneousness the projected protocol appears to be additional realistic than the obtainable one.

METHODOLOGY

There are many heterogeneous clustering protocols available today that are practically implemented. In this paper, we have studied, simulated and analysed the much appealing SEP and TSEP protocols.

1. Performance Measures

- Stability period: time interval before the first node dies.
- Network lifetime: time interval starting from the beginning of the operation of the WSN to the last node to go dead.
- Number of alive nodes per round: it is an instantaneous measure that reflects the total number of nodes that are active/alive in that round.
- Throughput: the number of packets sent over the network.

2. Stable Election Protocol (SEP)

In this section we refer to SEP, which enhances the stable region of the clustering hierarchy which uses the characteristic parameters of heterogeneity i.e. advanced nodes (m) and the added energy factor between the advanced nodes and the normal nodes (α). For the purpose of extending the stable region, SEP makes efforts to sustain the constraint of balanced consumption of energy in the sensor network. The advanced nodes have higher probability to become the cluster heads. Note that, the heterogeneous network with advanced nodes and normal nodes will have no effect on the network's spatial density, so the previously set P_{opt} does not change. But, the system's total energy will change. Each node knows the total energy of the sensor network in order to obtain the probability for it to be elected as a cluster head according to its remaining energy.

Now the stable region of the network can be increased by $(1+\alpha) \times m$ times, if

- Each normal node gets elected as a cluster head after every $1/P_{opt}\ (1+\alpha\ \times m)$ rounds.
- Each advanced node gets elected as a cluster head exactly $(1+\alpha)$ times after every $(1/P_{opt}) * (1+\alpha \times m)$ rounds. If the number of times that an advanced node becomes

a cluster head is not equal to $(1+\alpha)$, then the energy is not properly distributed and on an average, the number of cluster heads per each round will be less than the value $n \times P_{opt}$. It can be abridged by setting an optimal threshold $T(s)$. But, each node has to be elected as a cluster head as many times as its initial energy can be divided by the energy of a normal node.

SEP is a weighted protocol and hence assigns an optimum weight to the optimal probability P_{opt}

- This weight must be equal to the initial energy of each node divided by the initial energy of the normal node.
- Let the weighted election probability for the normal nodes be P_{nrm} and the weighted election probability for the advanced nodes is P_{adv}.
- In order to retain the energy consumed to be minimum in each round, the average number of cluster heads per round must be constantly equal to $n \times P_{opt}$.
- In the heterogeneous set-up, on an average the number of cluster heads per round is equal to $n \times (1 + \alpha \times m) \times P_{nrm}$. The weighed probabilities for normal and advanced nodes are given as:

$$P_{nrm} = P_{opt}/(1+\alpha * m) \qquad (1)$$

$$P_{adv} = P_{opt}(1+\alpha)/(1+\alpha * m) \qquad (2)$$

We define as T_{snrm} the threshold for normal nodes and T_{sadv} the threshold for advanced nodes. Thus, for calculation of threshold depending on their probabilities are:

$$T(i) = [P_{nrm}/(1\text{-}P_{nrm}[r \bmod (1/P_{nrm}])] \qquad if\ n \in G \qquad (3)$$

$$= 0 \qquad (otherwise)$$

$$T(i) = \left[\frac{P_{adv}}{1\text{-}P_{adv}\left[r \bmod \left(\frac{1}{P_{adv}}\right)\right]}\right] \qquad if\ n \in G \qquad (4)$$

$$= 0 \qquad (otherwise)$$

G is the set of nodes that have not become cluster heads within the last $1/P_{nrm}$ rounds, T_{snrm} is the threshold applied to a population of $n \times (1-m)$ (normal) nodes, This guarantees that each normal node will become a cluster head exactly once every $1/P_{opt}$ $(1+\alpha \times m)$ rounds per epoch, and that the average number of cluster heads per round per epoch is equal to $n \times (1-m) \times P_{nrm}$.

SEP Energy Analysis:

$$E_{int} = E_o \qquad (5)$$

$$E_{adv} = E_o(1+\alpha) \qquad (6)$$

$$E_{Total} = n*(1-m)*E_o + n*m*(1+\alpha) \qquad (7)$$

$$= n * E_o(1+\alpha * m)$$

where, E_o is the initial energy.

Threshold-Sensitive Stable Election Protocol (Tsep)

In this section we refer to the protocol TSEP (Threshold sensitive Stable Election Protocol)

TSEP has two major parts:

1. It is reactive routing protocol:

- Transmission consumes more energy than sensing.
- Done only when a specific threshold is reached.

2. It has three levels of heterogeneity:

- Normal Nodes
- Intermediate Nodes
- Advance Nodes

Advance nodes have energy which is greater than the energy of all the other nodes. Intermediate nodes have energy in between the energies of normal nodes and advance nodes and the remaining nodes are the normal nodes.

The network energy dissipation of TSEP is less due to energy heterogeneity of the model. There is a change of cluster at the start of each round. In case of TSEP, at the time of cluster change, the cluster head broadcasts the following parameters:

- Report Time (TR): Time period in which reports are sent by each node successively.
- Attributes (A): The physical parameters about which information is being sent by the sensor nodes.
- Hard Threshold (HT): An absolute value of the sensed attribute beyond which node will transmit the data to the cluster head. As and when the sensed value is equal to or is greater than this threshold value, node turns on its transmitter and sends the sensed information to the cluster head.

- Soft Threshold (ST): The smallest sensed value at which the nodes switch on their transmitters and start to transmit. All the nodes keep on sensing the environment constantly. As parameters from the attribute set reaches the defined hard threshold value, transmitter is turned on and the data will be transmitted to the cluster head. However, this condition is met only once for the first time.

The sensed value is stored in an internal variable in the node, called Sensed Value (SV). Again, for the second time and more, nodes will transmit the data if and only if the sensed value is greater than the defined hard threshold value or if the difference between the currently sensed value and the value that is stored in SV is equal to or is greater than the defined soft threshold. Hence, by keeping these both thresholds in consideration, the number of data transmissions is reduced, as transmission takes place only when the condition is met i.e. when the sensed value reaches the hard threshold.

The number of transmissions is lessened by the soft threshold, as it will eliminate the transmissions whenever there is even a small change in the value. Some of the important features are described below:

The main trade off of this system is that if the threshold is not reached, the user will not get any information from the network. Even if one node dies or all the nodes of the network die, the system will not be having any information about it.

The optimal probability of nodes, which are divided on the basis of energy, to be elected as a CH can be calculated by using the formulas:

$$P_{nrm} = P_{opt}/(1 + m * \alpha + b * \mu) \qquad (8)$$

$$P_{int} = P_{opt}(1 + \mu)/ (1 + m * \alpha + b * \mu) \qquad (9)$$

$$P_{adv} = P_{opt}(1 + \alpha)/ (1 + m * \alpha + b * \mu) \qquad (10)$$

We define as T_{nrm} the threshold for normal nodes and T_{adv} the threshold for advanced nodes. Thus, for normal nodes, we have:

$$T_{nrm} = P_{nrm}/1 - P_{nrm} * (r * mod/P_{nrm}) \quad if\ P_{nrm} \epsilon G` \qquad (11)$$

$$= 0 \qquad otherwise$$

$$T_{int} = P_{int}/1 - P_{int} * (r * mod/P_{int}) \quad if\ P_{int} \epsilon G`` \qquad (12)$$

$$= 0 \qquad otherwise$$

$$T_{nrm} = \frac{P_{adv}}{1 - P_{adv}} * \left(r * \frac{mod}{P_{adv}}\right) \quad if\ Pnrm\ \epsilon\ G``` \quad (13)$$

$$= 0 \qquad otherwise$$

Where, r is the current running round, G is the set of nodes that have not become cluster heads within the last $1/P_{nrm}$ rounds, T_{nrm} is the threshold applied to a population of $n \bullet (1 - m)$ (normal) nodes.

This guarantees that each normal node will become a cluster head exactly once every $1/Popt \bullet (1 + \alpha \bullet m)$ rounds, and that the average number of cluster heads per round per epoch is equal to $n \bullet (1 - m) \times Pnrm$.

TSEP Energy Analysis:

$$Total\ Energy\ of\ Normal\ nodes = Eo * (1 - m - b * n) \qquad (14)$$

$$Total\ energy\ of\ Intermediate\ Node = Eo * n * b * (1 + \mu) \qquad (15)$$

$$Total\ energy\ of\ Advanced\ Node = Eo * n * m * (1 + \alpha) \qquad (16)$$

$$Total\ Energy\ of\ the\ network = n * Eo * (1 + m * \alpha + b * \mu) \ (17)$$

$$Energy\ Dissipation\ of\ Cluster\ is, E(cluster) = E(CH) + E(non - CH) \qquad (18)$$

where,

$$E(non - CH) = L * E(elec) + L * \epsilon(fs) * d2(toCH) \qquad (19)$$

$$E(d2(toCH) = \int\int (x2 + y2)\,\rho(x, y)\,dxdy \qquad (20)$$

$$= \frac{M_2}{2\Pi k} \qquad (21)$$

where, $\rho(x, y)$ is node distribution

Simulation Results

The SEP and TSEP protocols are studied and analysed with respect to different parameters like throughput, residual energy, number of alive nodes and number of dead nodes per each round. The respective graphs are obtained as shown below.

Simulation Parameters:

Table 1: Considered parameters

Parameters	Value
Network size	$100m \times 100m$
Minimum initial energy	$Eo = 0.5\ J$
P(opt)	0.1
Transmit/Receive Electronics	$Etx = Erx = 50\ nJ/bit$
Transmitter amplification (free space signal)	$Efs = 10\ pJ/bit/m2$
Transmitter amplification (multipath fading signal)	$Emp = 0.013pJ/bit/m4$
Data aggregation	$Eda = 5nJ/bit/report$

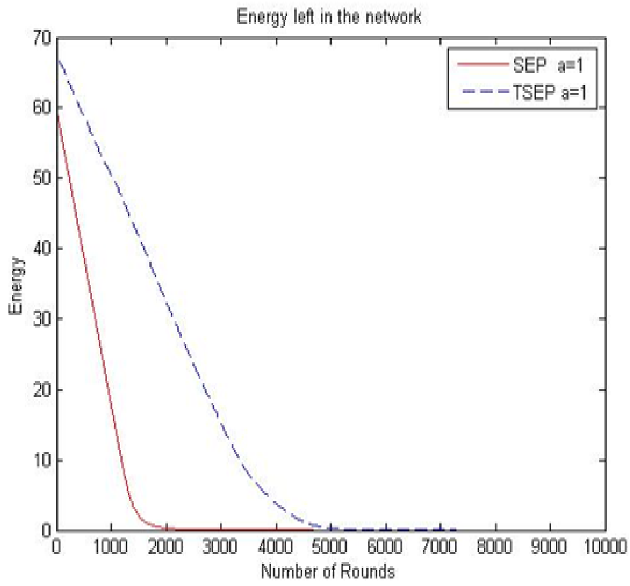

Figure 2: Residual Energy of the network.

The analysis was carried out for different number of nodes in the network and the results are as tabulated: For number of nodes:

Table 2: for 100 nodes, n=100

Protocol	First node dead after	Last node dead after	Throughput
SEP	998	4701	25076
TSEP	2785	7289	47615

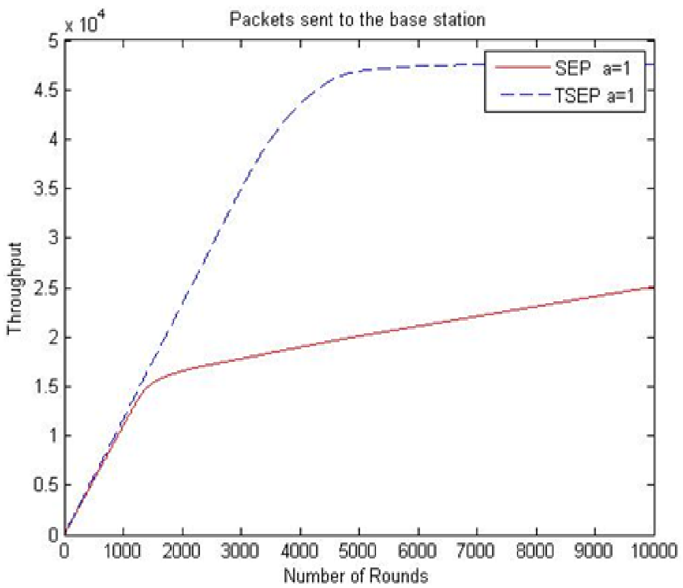

Figure 3: Throughput of the network

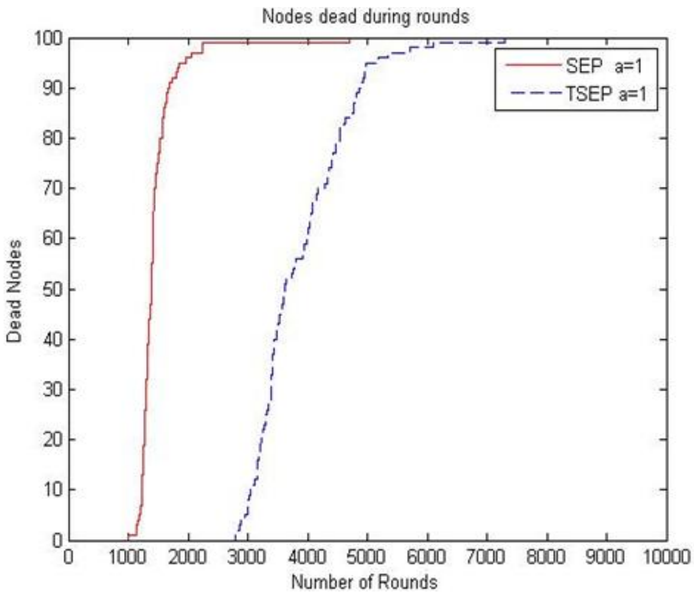

Figure 4: Number of nodes dead during each round.

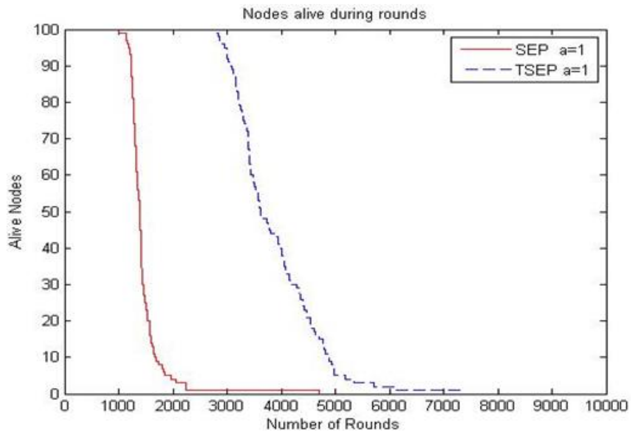

Figure 5: Number of nodes alive during each round.

Table 3: for 500 nodes, n=500

Protocol	First node dead after	Last node dead after	Throughput
SEP	1095	2853	87275
TSEP	2620	7566	243814

Table 4: for 1000 nodes,n=1000

Protocol	First node dead after	Last node dead after	Throughput
SEP	1112	2992	165642
TSEP	2531	8936	478002

CONCLUSION

The optimization of any wireless sensor network can be attained with the help of clustering. Any wireless sensor network can be made efficient and proficient by clustering. The heterogeneous clustering protocols more preferred depending on the application. Amongst the heterogeneous wireless sensor network protocols, two most prominent protocols- SEP and TSEP were studied, simulated in MATLAB and analysed. From the results of simulation, the graphs obtained and the above tabulation, it is visible that the throughput of TSEP is much better and improved than that of SEP. As we see, the number of nodes alive in TSEP is much greater than that of the number of nodes alive in SEP as the number of rounds increase and the number of dead nodes is in contrast to this. From this we can infer that the network lifetime is prolonged with the help of TSEP as compared to SEP. the energy left in the network after each round also affects the network. The residual energy is higher in TSEP than that of SEP after each round. From the above analysis, we can infer that for any number of nodes, TSEP is a more efficient clustering protocol than SEP.

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