Comparative Study of Hierarchical Routing Protocols in Wireless Sensor Networks

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ABSTRACT

WSN (Wireless sensor network) is composed of a large number of small, inexpensive, energy constrained nodes that are used to sense data for various civil and military applications. The sensed data from the environment is then propagated using various routing techniques to the base station. A sensor node becomes useless once its energy source i.e. the battery gets used up. To increase network lifetime, the main issue in wireless sensor networks is of energy conservation due to the fact that sensor nodes are kept in conditions and places that are inaccessible and left unattended. Network lifetime and energy conservation depends on using efficient routing techniques in wireless sensor networks, since energy is mostly used in transmission and reception of radio signals. Researchers have proposed many efficient routing protocols that can lower the energy consumption and thus increase the network lifetime. In this paper, we provide a comparative study of some popular cluster based hierarchal routing protocols using analytical simulation in MATLAB.

Keywords: Wireless Sensor Network, LEACH, TEEN, SEP, Network lifetime, Energy efficiency, Heterogeneity.

I. INTRODUCTION

Wireless sensor networks consists of hundreds and thousands of tiny, energy constrained devices called sensor nodes that collaborate together to sense a phenomenon and report any changes to the base station[1]. The data may propagate through multihop communication in the network to find its way to the base station. The basic unit, sensor node, consists of sensing unit, power supply, processing unit, and a transceiver that resides inside the communication unit. The data that is sensed by the node is kept stored in the storage unit and then transmitted through its transceiver via. radio signals. In case of cluster based hierarchal routing protocols CH (Cluster head) node accumulates all the data from the member nodes and then performs data aggregation, data fusion and forwards the data to base station.[7][20][24]

A wireless sensor network wide spread penetration in human lives is still hindered by the following challenges that need researchers' attention. These challenges taken into consideration also help design a robust functioning wireless sensor network.

- *Energy Constraint*: WSNs deployed in remote and inaccessible locations cannot have their energy source or battery replenished. The size of sensor node also does not allow residing large batteries within it. [1][24]
- *Quality of Service*: QoS requirement is of utmost importance as there are specific applications that need precision and real time monitoring of the required phenomenon. QoS characteristics such as delay and bandwidth needs to be taken into consideration. [25]
- *Fault Tolerance*: A sensor node may get dysfunctional as it is placed in harsh environment. In a fault tolerant system the remaining nodes must function properly and propagate the data to the base station.[1][22]
- *Scalability*: Covering a larger area is another issue in WSN. Researchers must consider applications scalable in terms of designing protocols and network. [13][14]

- *Density*: The sensor network may be made dense or sparse as per the requirements. Dense network has more QoS attributes whereas sparse may be used for cost effectiveness. Thus density requirements must be taken into account.[25]
- *Computational capability and programmability*: .The sensor nodes need to function quickly and adapt to environmental conditions. The nodes must be optimized in terms of programmability and update the software whenever necessary.[7][17]
- *Security:* Conventional security measures are not enough for WSN as they are Ad-hoc open networks. WSN are very vulnerable to attacks security concerns range from eavesdropping, repudiation to intrusion in the network[7]

Recent advancements in wireless technology have pushed WSN towards wide range of applications. Sensors have become smaller, less expensive, and more computationally capable. As a result WSN has found its application in nearly every sphere of human life. Due to all the developments in sensor technology and application in daily life WSN has become an extensive research topic. Most popular research topics in WSN include coverage, sensor node deployment, energy optimization, mobility at real time, localization, data collection, improving QoS concerns, cluster formation among many others.[23]

Our study is categorized into different sections: section II discusses the cluster based hierarchal protocols in wireless sensor networks. Section III covers the different simulation parameters. In section IV, the simulation results have been discussed. Section V covers the conclusion part.

II. CLUSTER BASED HIERARCHAL ROUTING PROTOCOLS IN WSN

As WSN deployment is done mostly in remote, inaccessible places that are devoid of human intervention thus network lifetime and energy efficiency become bottleneck issues. To address these problems efficient routing protocols have been proposed which use different routing techniques to optimize and balance energy dissipation in the network. This leads to better functioning and improved lifespan of the sensor network.[1][7]

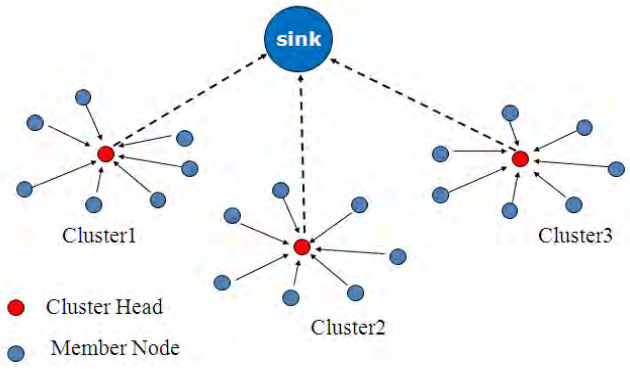

Fig. 1: Cluster formation in WSN [3]

In a hierarchical structure clustering is a technique that is used to address above mentioned problems. Whole of the network is divided into clusters. The main components of a cluster are the Base station (BS) and the Cluster head (CH). CH is the head of the cluster and is used for localized communication inside the cluster. The member nodes are in communication range of the CH. All the member nodes send their data to the respective CHs which then forward it using different routing techniques to the base station. Different clustering mechanisms are used to provide energy efficient routing and improving bandwidth and other QoS concerns. Below are some of the cluster based hierarchal routing protocols that we have simulated in MATLAB.

A. *LEACH:* LEACH (Low Energy Adaptive Clustering Hierarchy) is usually used in monitoring and surveillance applications remotely as the base station is located far from the sensor network. In LEACH the network is divided into clusters. In the setup phase, each cluster member makes a decision to become a CH based on stochastic probabilistic calculation [1].

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod p^{-1})}, & \forall n \in G \\ 0, & \forall n \notin G \end{cases}$$

Where n is a random number between 0 and 1, p is the cluster head selection probability and is the set of nodes that have not been CH for previous rounds. After the selection of CH advertisement of CH takes place. Based on RSS (Received Signal Strength) cluster nodes join the CH and cluster formation process completes. CH then makes TDMA schedules for cluster members for transmitting data. In steady phase data

transmission takes place based on previously allotted TDMA slots. Data is received by the CH, aggregated and then sent to the base station. LEACH is a proactive routing protocol where periodic data transmission takes place. The random rotation of CH helps in balancing energy dissipation and extends lifetime[1][5].

B. TEEN: A reactive routing protocol was developed by modification of LEACH called TEEN (Threshold sensitive Energy Efficient sensor Network) protocol. The member node transmits whenever there occurs a sudden change in the sensed phenomenon. Clustering phase is the same as in LEACH but after wards CH broadcasts two thresholds (hard and soft) based on which nodes send data. Sensing is done by the nodes on a regular basis but transmission takes place whenever attributes value exceed the threshold. TEEN finds application in time critical applications where periodic data transmission is not necessary. TEEN helps conserve energy as the transmitter is used sparingly for data transmission. It helps extend the lifetime of the wireless sensor network.[4][7]

C. SEP: SEP (Stable Election Protocol) takes into account the heterogeneity of the network. It increases the stable period of the protocol which is till the death of the first node. Heterogeneity may arise from initial setting of the network or as operation of the network proceeds. SEP is based on weighted election probabilities where each node may become a CH according to its remaining energy. LEACH does not take heterogeneity into account due to which LEACH is unable to exploit the nodes with higher energy. The epoh of CH nodes that are advanced and have more energy have been reduced so that they may become CH more often. The CH election formula has been modified which leads to better energy balance and improves the lifetime of the sensor network.[7][8]

III. SIMULATION

We have perform analytical simulation to evaluate and compare the performance of the selected protocols. Various simulation parameters are given in Table 1. We also define various performance metrics used for evaluation in our comparison of routing protocols.

A. Network performance parameters

Following network performance metrics are used for analyzing the simulation results:

1. *Network Lifetime*: It is defined as the time for which the network remains functional and till all the nodes die and stop transmission.
2. *Energy Consumption*: Amount of energy dissipated during transmitting (by member nodes) and receiving(by CH nodes) of packets by the nodes during the lifespan of the sensor network.
3. *Packets received at the Cluster Head node*: It is defined as the number of packets that are received at the CH successfully from the member nodes in the network.
4. *Stability Period*: It is the time for which the network is considered stable before the death of the first node (FND).

B. Simulation Parameters

In this section, various parameter setting that we have considered for our simulation are defined. The sensor network is deployed randomly and the base station is kept far away from the network at (50, 195). In SEP protocol, the heterogeneity parameters are taken as m=0.4 and a= 0.5 which means that 40% of the nodes have 50% higher energy than others.

TABLE 1: SIMULATION PARAMETERS

PARAMETERS	VALUES
Simulation Area Size	100 m x100 m
Number of nodes	100
Initial Energy of nodes	0.5 Joules
Percentage of CH (P_{opt})	5%
Data Packet size	4800 bits
Transmission & Receiving Energy (E_{elec})	50 nJ/bit
Free space Transmitter Amplifier Energy (E_{fs})	10 pJ/bit/m^2
Multipath fading Transmitter Amplifier energy (E_{mp})	0013 pJ/bit/m^4
Data Aggregation Energy (E_{DA})	5 nJ
Type of distribution	Random

IV. DISCUSSION OF SIMULATION RESULTS

The performance analysis of routing protocols is done in MATLAB. We have used the above discussed parameters for our simulation and now we compare them on the basis of the performance metrics defined earlier. The simulation results are shown as follows:

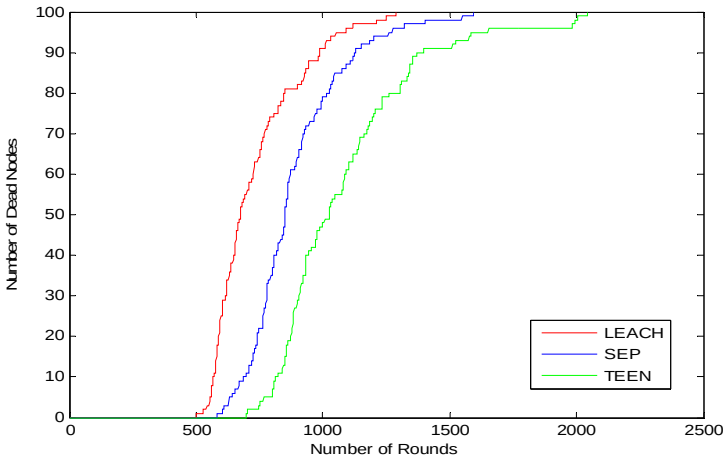

Fig. 2: Network Lifetime of Protocols

Fig 2 depicts the network lifetime for routing protocols with respect to number of dead nodes. The lifetime is calculated in terms of number of rounds that have progressed. We observe that TEEN has the highest network lifetime whereas LEACH has the least lifetime. It is because SEP makes use of heterogeneity of the nodes to balance energy whereas LEACH cannot make use of heterogeneity. In case of TEEN the sensor nodes end data reactively on the basis of thresholds which leads to least energy consumption and maximum lifetime of the sensor network. SEP has network lifetime of 21% more than LEACH whereas TEEN has a lifetime of 47% more than LEACH.

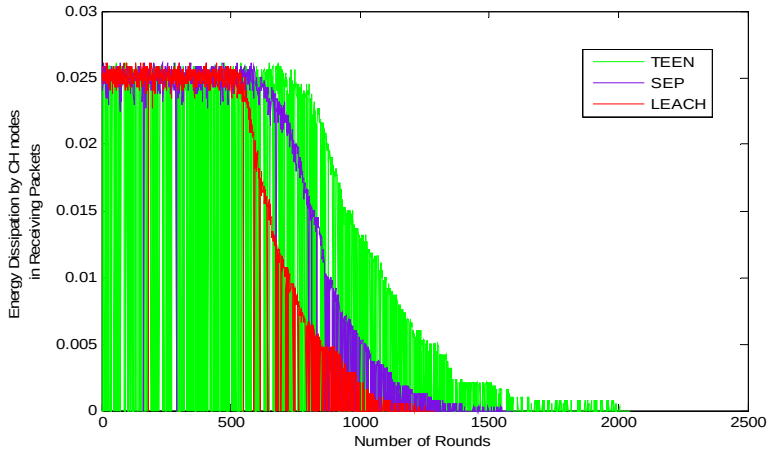

Fig. 3: Energy dissipation of CH nodes in Receiving packets vs Rounds

Fig. 3 shows the energy dissipation of cluster head nodes in receiving the data packets sent by member nodes in various protocols. The graph is plotted for nearly 2000 rounds which show that in TEEN the values plot down to zero (0) sometimes as transmission does not take place periodically. The sensor node only sends data when it transcends the threshold value allocated. The energy dissipation CHs of TEEN is the lowest as the member nodes do not send data periodically, whereas in case of LEACH and SEP periodic transmission takes place and energy consumption is higher than TEEN.

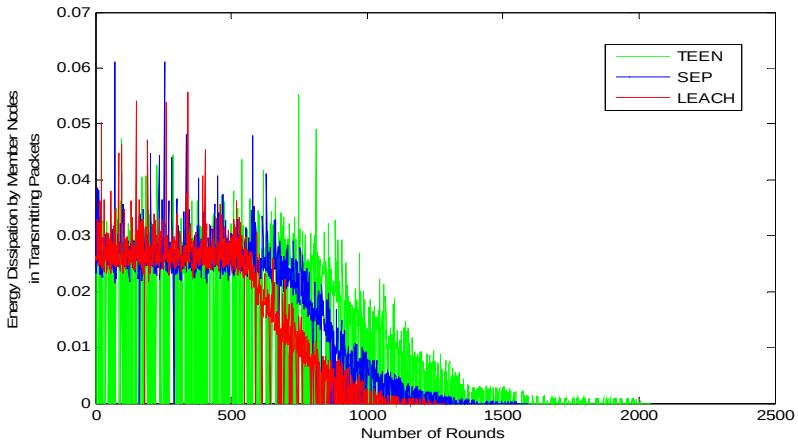

Fig. 4: Energy Dissipation by Member Nodes in Transmitting Packets vs Rounds

In Fig. 4 we observe the energy dissipation of member nodes in transmitting the data packets to the respective cluster heads. TEEN outperforms other protocols due to the fact that the member nodes continuously sense the environment but only switch-on their transmitter when the value sensed is beyond the threshold value.

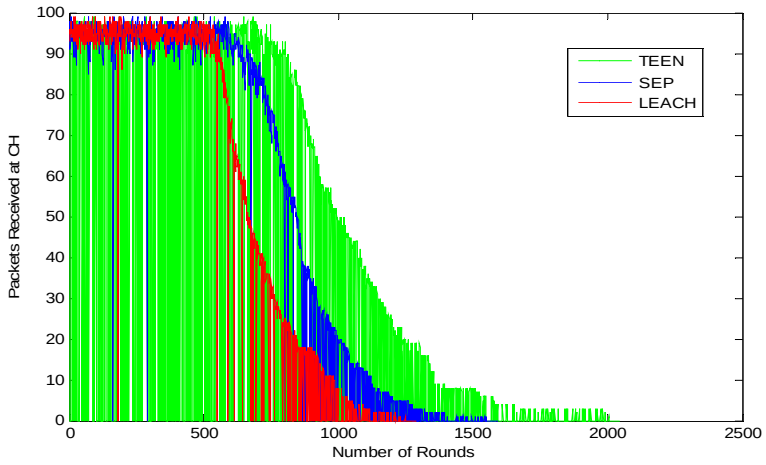

Fig. 5: Packets Received by CH nodes vs Rounds

Fig. 5 depicts the packets received at the respective cluster heads with respect to number of rounds. As TEEN is a reactive routing protocol and refrains from periodic transmission thus the packets received are least in TEEN. LEACH and SEP in this case have more packets and the measurements and readings of LEACH and SEP would tend to be more accurate than TEEN.

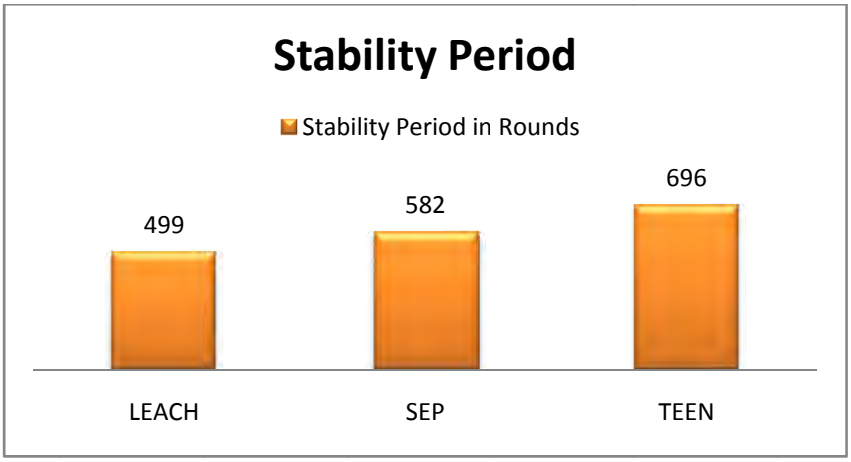

Fig.6: Stability Period of Protocols in terms of Number of Rounds

In Fig. 6 we have shown the stability period of the selected routing protocols, TEEN has better stability than LEACH and SEP due to less number of transmissions. SEP has better stability period due to balancing energy better and exploiting the heterogeneous environment than LEACH.

V. CONCLUSION

The main issue in designing of protocols for wireless sensor network is efficient use of energy for prolonging the network lifetime. In this paper we have discussed various challenges and issues for designing protocols in wireless sensor network. We have also performed a comparative analysis of popular cluster based hierarchal routing protocols (LEACH, TEEN and SEP) in wireless sensor network. This study would be useful to analyze which protocol would be used in which applications. The comparative study would also be useful for researchers in efficient designing of routing protocols. Table 2 summarizes our comparison made from the study.

Table 2: Comparison of Hierarchical Routing Protocols

Protocols	Type of Routing	Energy Efficiency	Energy of Nodes	Hierarchy Level	Network Lifetime	CH Selection Mechanism
LEACH	Proactive	Low	Homogenous	Single	Least	Probability based Threshold
SEP	Proactive	Low	Heterogeneous	Multiple (Bi-Level)	Moderate	Weighted Probability based Threshold
TEEN	Reactive	Very High	Homogenous	Single	Longest	Probability based Threshold

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