A Comparative study of Hierarchal Protocols for Wireless Sensor Networks (WSN)

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Abstract

Wireless Sensor Networks (WSN) are networks of highly distributed nodes which are deployed in very large number to detect an event or to measure certain physical parameters such as temperature, humidity, mobility, etc… with each node having its own battery. The main challenge in WSN mechanism is routing of packets in an energy efficient manner and hence to ensure this, several energy efficient routing schemes have been proposed in past. In this paper, author will discuss some of the cluster based routing schemes for WSN. Initially, author will begin by introducing WSN and their cluster based routing techniques in brief and then concluded with the comparison of those techniques on the basis of network lifetime, energy efficiency and various other parameters.

Keywords: Wireless Sensor Networks (WSNs), Cluster Head Selection in WSNs, Cluster-based routing protocols, Hierarchical clustering, WSNs routing protocols.

I. INTRODUCTION

WSN's are similar to mobile ad-hoc networks (MANETs) and it consists of large number of small nodes which are connected to each other through a wireless medium. These nodes are highly distributed and can communicate with their next hop neighbor to route the packet from source to sink. Every node possesses three components: (a) the sensor component used to sense the environment, (b) the processing component which performs computation on the data and (c) communication component which receives and transmits data to its neighbors.

The power required (P) by a node to transmit or receive packets is proportional to the data size (s) and the distance the packet needs to travel (d) [1].

$P = \theta * s * d$, θ – Constant -------- (1)

A node it a network transmits packets to the nodes in the network and receives packets to other nodes in the network. Therefore, the total amount of energy (E) that a node consumes in both transmitting and receiving packets can be expressed as [1]:

E = Σ (Power required to transmit data, Power required to receive data) -------- (2), or

$E = P1+P2$ -------- (3)

$E= (\theta*s1*d1) + (\theta*s2*d2)$ -------- (4)

The task of computation of the data and the communication between nodes with their next hop neighbors involves certain amount of power consumption. The sensor nodes are highly distributed in a certain geographical region and hence it becomes very difficult to monitor and maintain each node manually. The battery power and its consumption determines the network lifetime. Moreover, the inability of the nodes to recharge themselves makes the need of topology control and routing techniques as the vital factors in determining the network lifetime. Routing packets in an energy efficient manner results in increasing the lifetime of sensor networks but the selection of routing protocol more or less depends on the network topology. In flat topology the nodes in the network transmits the data to the sink in hops, where the contention among nodes is checked through power control or node scheduling but has scalability issues [2].

On the other side, hierarchal architectures are scalable and suitable for a highly dense sensor networks. A form of hierarchal topology control is to group the nodes in clusters. In any given graph G = (V,E); clustering is simply the identification of a set of subsets of nodes V_i , $i = 1, . . . , n$ in such a manner that $\cup_{i=1,...,n} V_i = V$ [3]. As shown in Fig 1, each cluster consists of a Cluster Head (CH); the responsibility of which is the controlling of the interactions or communications among the cluster members. Members of each cluster communicates with their respective cluster heads and all the data is collected, aggregated and fused by the cluster head thus reducing the power consumption. If required; the cluster heads may form another layer among themselves.

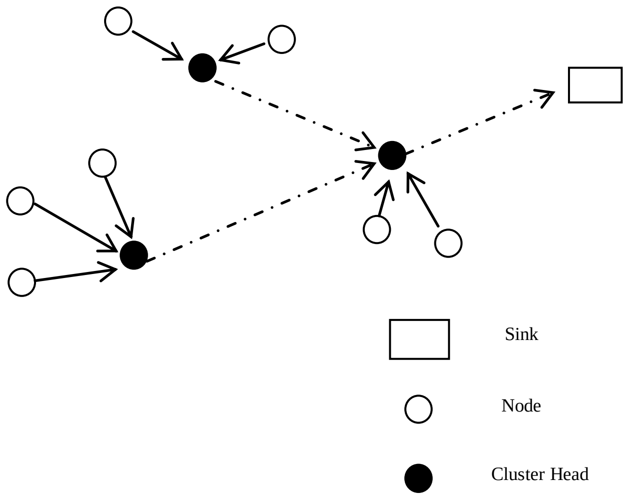

Fig. 1: A cluster based topology for WSNs

Clustering plays an important role in performance of the Wireless Sensor Networks and there are certain key attributes that should be taken into account before its implementations [4]:

- Cost of Clustering
- Selection of Cluster Heads and Clusters
- Real-Time Operation
- Synchronization
- Data Aggregation
- Repair Mechanisms
- Quality of Service (QoS)

II. HIERARCHAL ROUTING PROTOCOLS FOR WSN

1. LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) [5] is a clustering protocol which randomly distributes the energy load in the network. This even distribution of energy load is achieved by randomly rotating the cluster heads. After the formation of cluster head in the clusters, cluster head aggregates the data collected from the other cluster members and then directly communicate with the sink to relay the aggregated data. In LEACH the operations are carried out in rounds which comprise of two phases:

1) *Setup Phase* – cluster heads are selected which is followed by formation of clusters.
2) *Steady Phase* – cluster members and cluster heads communicate with each other by transmitting the data.

After each round, new cluster heads are selected on a random basis so that the energy consumption is evenly distributed across the network. Each node can individually decide whether it wants to become a cluster head. This decision making process is a function of the percentage of optimal cluster heads, frequency by which the node became cluster head and the last time when the node has been a cluster head. This threshold function can be defined as:

$$T(n) = \begin{cases} \dfrac{P}{1 - P\,[r \bmod (1/P)]} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

Where:

T(n) - Threshold function
n - A given node,
P - A priori probability of a getting elected as a cluster head,
r - Current round number and
G - Set of nodes that have not been elected as cluster heads in the last 1/P rounds.

During the cluster head selection processes each node generates a random number between 0 and 1. If this generated number is less than threshold function T(n), then that node becomes a cluster head for that cluster.

2. TEEN

Threshold sensitive Energy Efficient sensor Network protocol (TEEN), is a data-centric protocol suitable for time-critical applications [4]. Unlike LEACH, it is a reactive protocol which responds to the changes in the environmental parameters such as the temperature. In this scheme, initially clusters are formed and then the cluster heads broadcast two threshold messages to the nodes of their cluster [6]:

1) *Hard Threshold* – is the absolute value for the attribute to be sensed. If the sensed value is above the hard threshold then the node which sensed the value should switch on the transmitter and report it to the cluster head.

2) *Soft Threshold* – If any small change in the sensed value occurs, node itself triggers and switch on its transmitter and start transmitting the data.

In TEEN the node transmits data only when either the sensed value exceeds the hard threshold value or the change in the sensed value is greater than the soft threshold value.

3. APTEEN

Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) is an extension of TEEN and was developed to overcome the shortfalls of TEEN. With APTEEN WSNs can be reactive to time critical events and can also perform periodic data collection [7]. Here after the selection of cluster heads are made, each cluster heads broadcast four parameters:

1) *Attributes (A)* – These are the physical parameters like temperature, pressure, etc…which are to be collected.
2) *Thresholds* – These are of two types:
   (a) Hard Threshold
   (b) Soft Threshold
3) *Schedule* – It is a Time Division Multiple Access (TDMA) schedule and is used for assigning a slot to each node.
4) *Count Time* (T_c) **-** The maximum time period between two successive reports sent by a node and at times it is the multiple of the length of TDMA schedule.

4. PEGASIS

PEGASIS (Power-Efficient Gathering in Sensor Information Systems), aims at providing improvements to LEACH protocols. In PEGASIS, chains of nodes are constructed using the greedy algorithm instead of clusters to minimize the overheads [8]. In PEGASIS, it is assumed that each node has the global knowledge of the network and the chain construction begins from the nodes that are farthest from the sink. Each node in the chain only maintains the record of its nearest hop neighbors i.e. the previous and next neighbors. The communication in this chain occurs sequentially and each node aggregates the data received from its neighbor till the entire data is aggregate at a single node, which is the chain leader, which in turn controls the communication process by passing a token to the member nodes of the chain.

PEGASIS energy is conserved because:

- The maximum number of data messages that the head node receives is only two.
- The data is transmitted to the single hop neighbor who is nearest to the node.

III. COMPARISON OF DIFFERENT HIERARCHAL ROUTING PROTOCOLS FOR WSNs

Now we compare the hierarchal routing protocols discussed above on different parameters. Table 1 shows the comparison of the four protocols LEACH, TEEN APTEEN and PEGASIS. When it comes to energy efficiency PEGASIS is the most and LEACH is energy efficient protocol. PEGASIS provides performance enhancement of 100–300% over LEACH in energy consumption [8]. TEEN is slightly more energy efficient than LEACH and APTEEN performs lies somewhere between TEEN and PEGASIS. TEEN and APTEEN performs better than LEACH in terms of energy efficiency because of the fact that they transmits data on the basis of threshold value whereas LEACH transmits data continuously. All these four protocols have similar feature and architecture and have a fixed structure [9]. While LEACH, TEEN and APTEEN are cluster based algorithm PEGASIS is a chain based routing algorithm and avoids cluster formation. LEACH, TEEN and APTEEN selects the cluster heads randomly after each round of transmission while in PEGASIS a new chain leader is elected after each round of transmission.

Protocols	**Energy Efficiency**	**Scalability to Heterogeneous Network**	**Cluster Head Selection**	**Network Lifetime**
LEACH	Average	Low	Random	Average
TEEN	Good	Medium	Random	Good
APTEEN	Good	High	Random	Good
PEGASIS	Excellent	High	Absent	Good

Table 1: Comparison of Hierarchal Protocols for WSNs

IV. CONCLUSION

In this paper, we have discussed the four common hierarchal routing protocols LEACH, TEEN, APTEEN and PEGASIS. Although these protocols have been widely used for WSNs where each of them is having their own disadvantages. In WSN, since the energy of node is limited, it plays an important role in designing the routing protocol.

LEACH involves continuous transmission of data and thus it is not very energy efficient. Moreover, LEACH is only suitable for Homogenous networks. In heterogeneous networks, each node has a different residual energy. TEEN although is more energy efficient than LEACH, however, it is not suitable for sensor networks where periodic sensor readings should be delivered to the Sink, as it may be the case that the values of the attributes never crosses the threshold limit at all. As in TEEN, there are some unused or wasted time-slots, therefore sometimes sink may or may not be able to distinguish between dead and alive nodes [3]. Moreover, if cluster heads are not in each other's transmission radius, the messages will be lost. Although APTEEN offers flexibility of allowing the user to set the time interval, its main drawback is that it is complex to implement. Even though PEGASIS reduces the number of transmission in cluster heads, however, it involves excessive data flow which may lead to congestion in wireless sensor network. Its operation also involves significant delays as the data is transmitted sequentially in the chain and the chain leader has to wait till it receives all the messages before communicating with the sink. In PEGASIS all the information is aggregated into a single unit, which may result in delivering accurate information to the sink.

All the four protocols discussed in the paper do not consider neither the residual energy of the node and nor the location of the base station. As a result of which, sometimes a node with insufficient battery power can be selected as the cluster head which may result in the transmission failure. Therefore, there is a need to design a protocol which selects the cluster heads on the basis of both the residual energy and its location from the base and which also eliminate all the overheads related to the cluster head selection. There are various proposed algorithms that address this issue but their results are often having adverse effect on energy efficiency and lifetime of a network. In addition to these, further improvements in reliability needs to be examined in terms of possible modifications in the clusters which can result into re-clustering, which involves cluster head selection.

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