COMPARATIVE STUDY OF ENERGY EFFICIENT ROUTING PROTOCOLS IN HIERARCHICAL CLUSTER BASED WSN

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Abstract: Wireless Sensor Networks (WSNs) consists of a large number of small sensor nodes. These nodes are small in size and operated by low power batteries. Due to this low power the energy conservation is one of the important goals while designing Routing Protocols for WSNs. In a hierarchical cluster based WSN, cluster heads (CHs) receive and aggregate the data from the members of cluster, aggregate the data and transfer it to base station. To complete these tasks cluster heads consume more energy in comparison to other nodes. To save the energy of sensor nodes and improving the lifetime of WSNs, the proper selection of CHs is very important. In this review paper we are studying different energy efficient hierarchical cluster based routing protocols that are used in WSNs to get the understanding of these protocols and compare them especially for their energy conservation policies. Here we are focusing on LEACH (Low-Energy Adaptive Clustering Hierarchy), TEEN (Threshold sensitive Energy Efficient sensor Network protocol), APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network Protocol) and TSEP (Threshold sensitive Stable Election Protocol).

Index Terms – WSN, Hierarchical, Cluster, Routing Protocols, LEACH, TEEN, APTEEN, TSEP.

I INTRODUCTION

Wireless Sensor Network (WSN) is a category of wireless networks in which a large number of sensor nodes are spatially distributed in a geographical area. These nodes sense the environmental attributes and send the sensed data to Base Station (BS). Nodes consist of sensing unit, processor, transceiver and small battery. It is impractical to replace or recharge batteries of all deployed nodes [3]. Nodes may transmit data in coordinating fashion either using intermediate nodes or hierarchical fashion to BS. In hierarchical scheme Cluster Heads (CHs) are elected as intermediate nodes. CHs are the nodes performing extra duties of data collection and forwarding. WSNs are categorized on the bases of different parameters. In terms of energy, WSNs can be divided into homogeneous or heterogeneous networks. In former networks all nodes have same initial energy while in later nodes can have different energy. In terms of sensing and transmitting the data these networks are classified into following two types:

- **Proactive:** In proactive networks nodes sense the attributes and send it, in its corresponding time slot, without any restrictions. These networks are suitable for applications which require continuous monitoring.

- **Reactive:** Nodes in reactive schemes sense the attributes continuously but transmit the data only if sensed attributes reached to a certain threshold value.

Routing protocols in WSN can be divided on the basis of network structure as well. Network structure can be either flat, hierarchical, or location based. Hierarchical clustering schemes are further divided into two categories:

- **Static Clustering:** Network area is divided into fixed regions and nodes remain in same region throughout the network life time.

- **Dynamic Clustering:** At the start of each round, nodes associate themselves with the elected CH.

Energy hole and coverage hole challenges in WSN have become a strong area of research. Energy hole is created due to premature death of data forwarding nodes, i.e. hot spots. Researchers have proved that problem of coverage hole is minimized using static clustering schemes [5]. Coverage holes are created due to uneven deployment of nodes or premature death of intermediate nodes i.e. energy hole.

There are numerous applications of WSN in military, health, industry environment and other areas of life [2]. Its applications can also be seen as, area monitoring, health care monitoring, forest fire detection, machine health monitoring, water level detection. In this work, we are studying different hierarchical clustering based routing protocols and compare them on the basis of different parameters. Rest of the paper is organized as: Section 1 describes introduction, in section 2 hierarchical clustering is

explained, in Section 3 different routing protocols of WSN discussed, comparison of different routing protocols done in section 4, and finally in section 5, Conclusion and future work is described.

II HIERARCHICAL CLUSTERING IN WSN

First time hierarchical clustering is introduced by Heinzelman et al. in [1]. In their model all the sensor nodes are homogeneous with same initial energy. There is a base station (BS) in the hierarchy that may be at a distance from the other nodes and has a constant power supply. So it does not have any energy constraints. Base station can transmitted to all nodes directly with high power. However due to their power constraints, nodes cannot directly reply to BS. So the communication is not symmetric [5].

In hierarchical clustering scheme the whole network is divided to a number of clusters. Each cluster contains the nearby nodes in a geographical area and has a cluster head (CH). CH collect data from the members of its cluster, aggregate data and transmitted it to base station or an upper level cluster head. These cluster heads in turn form a higher level cluster and one of these selected as cluster head. Same pattern is continued to form a hierarchy of clusters. The base station is act as the root of this hierarchy and manages the entire network. The next level cluster heads reported to base station directly [6]. The user gets the required information from the base station only.

The main features of hierarchical clustered architecture are:

1. Transmission of data taken place from node to the immediate cluster heads only that saves the energy.
2. Energy again conserved by performing the aggregation only by the cluster heads.
3. As the CHs nearby the BS depleted their energy faster than other nodes, so to evenly distribute the consumption all the nodes in turn become CH for limited time interval T, called the cluster period.

III ROUTING PROTOCOLS IN WSN

There are various types of routing protocols available for WSN. It is out of scope of this paper to discuss all these protocols in detail. Here we are focusing on some of hierarchical clustering based energy efficient routing protocols. We are discussing four major energy efficient protocols that are LEACH, TEEN, APTEEN and TSEP.

3.1 Proactive Network Protocol: LEACH

LEACH (Low Energy Adaptive Clustering Hierarchy) was introduced by Hienzelman [1]. Leach is the initial hierarchical routing methods for sensor networks [4]. This protocol is very energy efficient routing protocol. LEACH is self organizing, flexible clustering protocol [5]. It reduces power use and reduces energy indulgence in a sensor network. It is a cluster-based protocol and clusters are elected on circular basis [4]. The WSN's are divided into the clusters and every cluster consists of a cluster head. LEACH randomly select sensor nodes as cluster heads and rotates this role to balance the energy load among sensors in the network.

As indicated by this protocol the base station is settled and situated a long way from the sensor nodes and nodes are homogeneous and energy constrained. Here one should be called cluster head goes about as the nearby base station. Leach discretionarily turns the high-energy cluster head so the occasions are similarly shared between the sensors and the sensors consume battery control similarly. In LEACH cluster head node pack information touching base from nodes (those that have a place with the separate clusters) and sends a collected parcel to the base station to diminish the measure of data that must be transmitted to the base station [4]. Leach operation is partitioned into two stages; they are setup stage and steady stage. In the principal stage, the sensor nodes are composed to frame progressive basic plan, which can either be in a cluster based or chain based way and in the second stage when information are steered from sensor nodes to the base station .

The hierarchical structural design of a cluster can be set up by utilizing conveyed distributed algorithm or centralized algorithm. The leach has two phases. One is Setup phase and next is Steady Phase.

In Setup phase node send messages to other cluster nodes advising them to transmit their status. CHs are elected on the basis of energy and non-CH nodes pick the CH to join cluster. CH makes plans and sends them to cluster nodes. Nodes send data to particular CH nodes for the rest of the bit of the round which CHs aggregate and transmit to a BS (base station).

Steady state phase has few frames and a frame is split into two time slots. A time slot for SN (sensor nodes) and another for CH. SNs transmit data to CH in the time slot for SN. The CH packs data and transmits to BS. As cluster works in a frame unit, it declines to work in the rest of the time [2]. Leach utilizes a one-hop routing where every node can transmit specifically to their cluster head or sink. LEACH is not fit for being disseminated in the substantial zone.

Important Features

Key features of LEACH are [1][3]

1. Restricted synchronization and control for cluster setup and operation.

2. Arbitrary rotation of the clusters or cluster heads.
3. Indigenous firmness to worldwide communication.

LEACH reduces energy consumption as it control unimportant communication between sensors and their cluster heads and turning off non-cluster nodes as much as possible [2].

In spite of the fact that LEACH has indicated great highlights to sensor networks, such as clustering architecture, confined coordination and control, randomized rotation of cluster head, and local compression to reduce global communications (energy consumption minimization), it suffers from the following drawbacks [7].

It can't be connected to time compelled application as its outcomes have some latency. The nodes on the route to the sink could deplete their energy quickly. This issue is known as hotspot issue. The number of clusters may not be fixed, so it is not suitable for large sensor networks.

3.2 Reactive Network Protocol: TEEN

TEEN (Threshold sensitive Energy Efficient sensor Network protocol) proposed by Manjeshwar et al [8]. This protocol is design for reactive networks; transmit the critical data to user instantly. It uses dynamic clustering and every time when Cluster Heads are elected, they broadcasts following two thresholds to the members of cluster along with attributes parameters:

Hard Threshold (HT): It is the threshold value of attribute parameters, if the node senses the value beyond Hard Threshold then the node switch to its transmitter and transmit sensed data to its cluster head.

Soft Threshold (ST): This is a another threshold value of attribute parameters, if the change in the sensed value cross this threshold then again node switches to its transmitter and transmit sensed data to its cluster head.

In this scheme nodes sensed environment continuously but do not transmit sensed data immediately to the Base Station. First time a node transmits data when a parameter of attribute set reaches to its hard threshold value. The node stores this sensed value (SV) in an internal variable of the node. In the current cluster period, node will transmit data again, if following two conditions are meet:

1. The current sensed value of the parameters of attribute set is greater than the hard threshold (HT).
2. The difference between the current sensed value of attribute and stored value SV is more than or equal to the soft threshold value.

After transmitting data, SV is set to the current sensed value of the attribute. This scheme reduces the number of transmissions because transmission is taken place only if the sensed data is in the range of interest of the user.

Important Features

The main features of TEEN are as follows [8]:

1. This scheme is well suited for time critical data sensing applications because the time critical data reaches to the user instantly.
2. Energy consumption is very low in comparison to proactive networks as the data is transmitted less recurrently.
3. User can set the soft threshold according to the criticality of sensed data and application.
4. A smaller value of the soft threshold provides more accurate information about the attributes, at the expense of increased energy consumption. Thus, the user can make a balance between energy efficiency and correctness.
5. It provides flexibility to the user to choose the new set of attribute values as per their requirement, every time when clusters are elected.
6. It is well suited for time critical applications such as intrusion detection, explosion detection etc.

The main negative aspect of TEEN is that, if the parameter values not reached thresholds, the nodes will never communicate. As the user does not have any correspondence within the network, it will never come to know even if all the nodes die. Hence, this protocol is not well suited for applications where the user required data on a regular interval of time. One more drawback of TEEN is that there may be collisions in the cluster. To avoid these collisions TDMA or CDMA scheduling of the nodes can be used.

3.3 Hybrid Network Protocol: APTEEN

APTEEN ("Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network Protocol") designed for hybrid networks by Manjeshwar el al [11]. In APTEEN Cluster Heads are elected for a small period of time. Once the CHs are elected, they broadcast the following parameters to their members:

Attributes (A): The CHs broadcast a set of physical parameters of the attributes for which user want to collect data.

Thresholds: With the physical parameters, CHs also broadcast two thresholds on the parameters, a hard threshold (HT) and a soft threshold (ST). HT is a value of an attribute decided by user. If sensed data value of an attribute cross this threshold, the node will be triggered to transmit data first time. ST is another threshold value of an attribute, also decided by user. When the change in the value of a parameter is more than ST then node triggered to transmit data thereafter.

Schedule: In APTEEN, TDMA scheduling is used. Here we assign [8] a fixed slot to each node.

Time Count (TC): This is a time period, broadcasts by the CHs. TC decide the maximum time period between two successive transmissions from a node.

The data values exceed the threshold values are referred as critical data. In a sensor network mostly close by nodes is the part of same cluster. As they are in same region, they sense similar data and try to send critical data simultaneously. This situation can cause collisions. To solve this problem APTEEN introduce a TDMA schedule that assigned a transmission slot to each node in the cluster. APTEEN also introduce time count that decides the maximum time period between two successive transmissions from a node. This solves the problem of not transmitting any data if sensed data never cross threshold value. Sensed data must be transmitted if it is not transmitted in last time count duration.

Important Features

The main features of APTEEN are [11][12]:

1. It combines both proactive and reactive network policies. By transmitting periodic data it follow proactive policy and provide complete picture of network to the user. By responding immediately on drastic change it follows reactive policy and provides quick response in time critical situations.
2. This policy provides flexibility to the users by allowing them to choose the time interval (TC) and the threshold values for the attributes.
3. By changing threshold values and time interval energy consumption can be controlled.
4. The hybrid network can imitate as a proactive network or a reactive network, by suitably choosing the time count and the threshold values.

The main negative aspect of this scheme is the requirement of additional complexity to implement the threshold functions and the time count. But, this complexity can be acknowledged due to its features that provides additional flexibility and versatility.

3.4 Reactive Network Protocol with Heterogeneity: TSEP

TSEP (Threshold sensitive Stable Election Protocol) developed by Kashaf et al. [13], is also a reactive routing protocol like TEEN, a transmission perform only when parameters reached to threshold but it also uses three levels of heterogeneity. For three levels of heterogeneity, nodes with different energy levels are used considered as 'Normal Nodes', 'Intermediate Nodes' and 'Advance Nodes'.

Advance nodes having highest level of energy, intermediate nodes having energy in between normal and advance nodes while the nodes with least energy level are considered as normal nodes. Intermediate nodes are selected by using b, a fraction of intermediate nodes to all living nodes and using the relation that energy of intermediate nodes is μ times more than that of normal nodes. Nodes are selected as CH on the basis of probability. This probability is calculated with the help of remaining energy of nodes.

However, average number of CHs in TSEP is not much different from LEACH but due to energy heterogeneity energy indulgence is reduced. At the start of each round, new clusters are formed. In case of TSEP, at cluster change time, the CH broadcasts the following parameters

Report Time (TR): Time period during which reports are being sent by each node successively

Attributes (A): The physical parameters about which information is being sent.

Hard Threshold (HT): An absolute value of sensed attribute beyond which node will transmit data to CH. As if sensed value becomes equal to or greater than this threshold value, node turns on its transmitter and sends that information to CH.

Soft Threshold (ST): The smallest sensed value at which the nodes switch on their transmitters and transmit.

Sensing environment and data transmission to CH, is happened in the same way as in TEEN and APTEEN, first time when the HT value is reached, the sensed attributes are transmitted and also stored in an internal variable in the node, called Sensed Value (SV). Afterwards, data transmission from nodes will be taken place if and only if the sensed value of the parameter is greater than hard threshold or if currently sensed value differs from the value stored in SV variable by soft threshold. So, by using both thresholds, the number of data transmissions can be reduced.

Important Features

Main features of this scheme are [13]:

1. Like TEEN this scheme is also well suited for time critical data sensing applications because the time critical data reaches to the user instantly.
2. Energy consumption is less than that of proactive networks (LEACH) as data is not transmitted so repeatedly, however nodes sensed the environment continuously
3. At time of cluster change, user can set the attributes, report time and thresholds according to the criticality of sensed data and application.
4. Like TEEN it also provides flexibility to the user to choose the new set of attribute values as per their requirement, every time when clusters are elected.

The negative aspect of this scheme is also same as TEEN. If the parameter values not reached to thresholds, the nodes will never communicate. As the user does not have any correspondence with the network, it will never come to know even if all the nodes die. Hence, this protocol is not well suited for applications where the user required data on a regular interval of time.

IV COMPARISON

Compared with LEACH, TEEN reduces the overheads of energy consumption due to continuous transmissions. The hard and soft thresholds reduce the number of transmissions by always allowing the nodes to transmit only when the sender information is in the range of interest or there is a remarkable change in the attribute. So energy consumption in TEEN is not so much as in pro active networks like LEACH. TEEN is well suited for time critical applications and quite effective in terms of energy consumption and response time as compared to LEACH. However in TEEN and TSEP if thresholds are not reached, the node will not communicate and user will never get any information from network at all and will not come to know even if all the nodes die. APTEEN is an improvement of the TEEN that overcome this problem by introducing count time. Count time is the maximum

Table 1: Comparison of different routing protocols for WSN

Parameters	LEACH	TEEN	APTEEN	TSEP
Energy Efficiency	Low	Very High	High	High
Network Lifetime	High	Very High	High	Very High
Data Aggregation	No	Yes	Yes	Yes
Cluster Stability	Medium	High	Low	Low
Scalability	Very Low	Low	Low	Medium
Type of Network	Proactive	Reactive	Hybrid	Reactive
Transmission Model	Cluster Head	Active Threshold	Demand Driven	Active Threshold
Transmission Delay	Very Small	Medium	Small	Medium
Overheads	High	High	Medium	Medium
Clustering Methods	Dynamic	Dynamic	Dynamic	Dynamic
Energy of Nodes	Homogeneous	Homogeneous	Homogeneous	Heterogeneous
Power Usage	High	Medium	High	Medium

time period between two successive reports send by a node. APTEEN is a hybrid clustering based routing protocol. It transmits the data at regular intervals as well as responds to any speedy change in the estimate of any attribute value.

TSEP is also a reactive routing protocol like TEEN. It also transmits only when the specific threshold is reached but this protocol use three levels of heterogeneity. Unlike other three protocols in TSEP nodes are not homogeneous. As TSEP is heterogeneity aware protocol energy dissipation is controlled to some extent and stability and network lifetime is also improved.

V CONCLUSION

The objective of this paper is to study the energy efficient routing protocols that keep the sensor nodes working for a maximum possible period of time and in this way expend the network lifetime. In this paper we have examined different issues, major key features and drawbacks of different routing protocols. We have done comparative study of the four major energy efficient hierarchical clustering based routing protocols that are LEACH, TEEN, APTEEN and TSEP, on the basis of different parameters. Energy efficiency is the major issue of our study. The comparative study of these classical protocols will help us to understand the recent research work in the field of energy efficient routing in WSN and in future we can proposed a new hierarchical clustering based protocol which may be more helpful in energy efficiency.

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