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Review of Cluster-based Energy Routing Protocols for WSNs

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Abstract—This paper presents various Hierarchical Clustered based routing protocols of the WSN in the literature and explains its benefits. These protocols are designed to prolong the lifetime of network by minimizing the energy consumption of the sensor nodes. We scrutinize and compare several aspects and characteristics of few widely explored hierarchical clustering protocols, and its processes in wireless sensor networks (WSN). This paper also presents a discussion on the future research topics and the challenges of hierarchical clustering in WSNs.

Index Terms: Wireless Sensors Networks, Cluster, Cluster Head, Energy-efficiency.

I. INTRODUCTION

The technological advances in microelectronic mechanical systems (MEMS) have enabled the development of tiny, low-cost, low-power, and multifunctional smart sensor nodes in a wireless sensor network (WSN). Wireless Sensor Networks (WSNs) have been widely considered as one of the most important technologies for the present age. These smart sensor nodes are deployed and networked through internet and wireless links. A WSN typically consists of a large number of low-cost, low-power, and multifunctional sensor nodes that are deployed in a region of interest. These sensor nodes are small in size, but are equipped with embedded microprocessors, radio receivers, and power components to enable sensing, computation, communication, and actuation. These components are integrated on a single or multiple boards, and packaged in a few cubic inches. These sensor nodes typically have several parts: Main components of a node are as under

- Sensor
- Processor
- Radio Transceiver
- Power Unit.

Additional Components may include

- Location Finding Unit
- Mobilizer
- Power Generator, a
- Storage Unit
- Analog-to-Digital Converter (ADC) and Digital-to-Analog Converter (DAC)

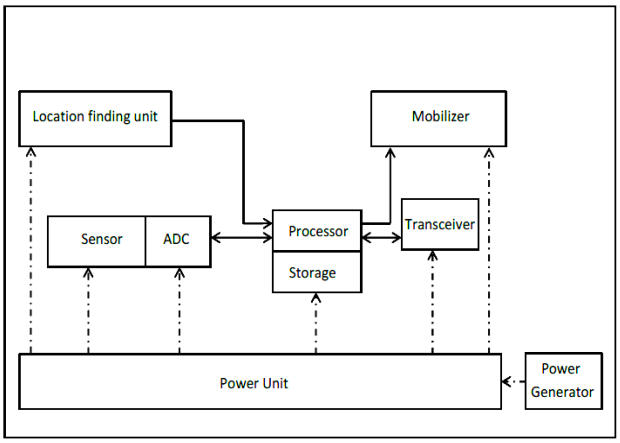

Figure 1: Hardware Architecture of a Node

As a new information acquisition and processing technology, wireless sensor network (WSN) has a wide range of applications in military, environmental monitoring, forest fire monitoring , volcanic eruption, green house monitoring , commercial appliances at home and at industries, space exploration and so on .

Based on these serious expectations, in several significant WSN applications the sensor nodes are remotely deployed randomly in larger numbers and operated autonomously. In these hostile, unattended environments the sensors cannot be charged and replaced, thus energy constraints are the most serious problem so that it must be considered.

Usually routing protocols on the basis of network structure are divided into four main groups: Location-based , Data-Centric , QoS-Aware and Cluster-based Hierarchical routing. In order to support data aggregation through well-organized network group, nodes can be divided into an amount of small groups called clusters. All the clusters are being managed by Cluster Heads and rest of the nodes are known as member nodes. In the cluster-based hierarchical model, data is first aggregated by the cluster head and then sent to a higher-level cluster-head. As it moves from a lower level to a higher one, it travels larger distances, therefore decreasing the travel time and latency. The idea of hierarchical routing is to achieve energy-efficient routing in WSNs and hence extend the network lifespan. The formation of clusters and assigning

tasks to cluster heads can contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS.

II. Related Work

In this section, related work from literature about is presented in detailed.

A. *Low energy adaptive clustering hierarchical (LEACH)*

LEACH is a clustering based hierarchical protocol. In this protocol the network is organized into clusters that suggests distributed and centralized schemes . Clusters are being managed by cluster head node. CH is chosen from the nodes in the network based on their receiving signal strength. After each round the cluster head rotates which collects the data from other nodes in the cluster and send the data to the sink results in uniform consumption of energy across the network.

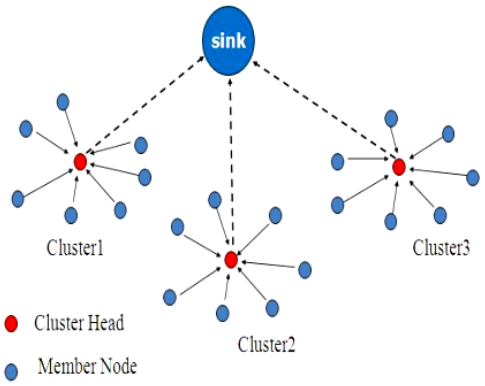

Figure 2: Basic Topology of LEACH

$$T(n) = \begin{cases} \dfrac{P}{1 - P\left[r * mod\left(\frac{1}{P}\right)\right]} & if\ n \in G \\ 0 & otherwise, \end{cases}$$

In each cluster CH performs the data aggregation and minimizing the redundunt iformation in order to send optimal messages to sink. Here in this particular approach each node selects a random value 0 and 1. The nodes whose random value is less than the threshold those nodes are chosen as cluster head for current round only where P=desired percentage of cluster heads, r=current round and G is the set of nodes that have not been cluster heads in the last 1/P rounds. The nodes that are cluster head in round 0 cannot be cluster head for the next 1/P rounds . Various modifications have been made to the LEACH protocol such as TL-LEACH [6], E-LEACH [7], M-LEACH [8], LEACH-C [9], V-LEACH [10], LEACH-FL [11], T-LEACH [12]. Here, we present the strengths and weaknesses of LEACH protocol.

a. Strengths:

a) Data aggregation

b) Uniformly distributed Energy consumption

c) Collision avoidance

d) Load balancing

e) Prolongs Network lifetime

f) Low Probability of Energy Holes

b. Weakness

a) Low energy nodes can be selected as CH.

b) CH selection is randamoized may result in faster death of some nodes.

B. *Hybrid Energy-Efficient Distributed Clustering (HEED)*

Hybrid Energy-Efficient Distributed clustering is improved from of LEACH specifically in the election of CH; Randmoised approach for the CH is not used in HEED. Cluster formation is performed based on the hybrid combination of two parameters. One parameter depends on the node's residual energy and the other parameter is the intra-cluster communication cost. In HEED, elected CHs have relatively high average residual energy compared to member nodes. In HEED, a percentage of CHs among all nodes, Cprob is set to assume that an optimal percentage cannot be computed a priori. The probability that a node becomes a CH is:

CHprob= Cprob Eresidual/Emax (3)

where Eresidual is the estimated current energy of the node, and Emax is a reference maximum energy, The value of CHprob is not allowed to fall below a certain threshold that is selected to be inversely proportional to Emax. Afterwards, each node goes through several iterations until it finds the CH. If it hears from no CH, the node elects itself to be a CH and sends an announcement message to its neighbors. There are two types of status that a sensor node could announce to its neighbors: tentative status and final status. If its CHprob is less than 1, the node becomes a tentative CH and can change its status to a regular node. If it's CHprob has reached 1, the node permanently becomes a

CH. In HEED, every node elects the least communication cost CH in order to join it.

1. Strenghts

a) It improves network life time.

b) The cluster head selected in the heed are well distributed across the network and the communication cost is minimised.

2. Weakness

a) The cluster head selection deal with only a subset of parameters, which can possibily impose constraints on the system. These methods are suitable for prolong the network life time rather then for the entire WSN.

C. Threshold-sensitive energy-efficient sensor network protocol (TEEN)

TEEN is a hierarchical clustering protocol, it uses multi level hirarichey concept, which sets sensors into clusters with each managed by a CH. The data sensed by sensors is send to their respective CH. The CH aggregated the data and send ot to next level CH until the data reaches the sink. Thus, the main idea behind TEEN network architecture is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the BS (sink) is reached.

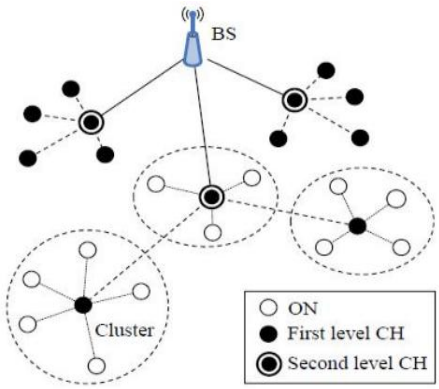

Figure 3: Basic Topology of TEEN

Here, in this scheme, two threshold values are broadcast to the nodes: hard threshold and soft threshold etc. The hard threshold is the least possible value of an attribute. Sensor nodes send data to the cluster head only if they found the sensed value is greater than the hard threshold ,If sensor nodes found that the sensed value is less than the attribute value of threshold than they do not send the data to the cluster head. By this way only relative data is send by the sensor nodes. Next time when sensor node again sense value greater than the hard threshold value than they check the difference between current and earlier value with soft threshold. If the difference is again greater than the soft threshold than the sensor nodes will send recent sensed data to the cluster head. This process will remove burden from the cluster head.

1. Strengths

a) TEEN is useful for applications where the users can control a trade-off between energy efficiency, data accuracy, and response time dynamically. TEEN uses a data-centric method with hierarchical approach.

b) Important features of TEEN include its suitability for time critical sensing applications. Also, since message transmission consumes more energy than data sensing, so the energy consumption in this scheme is less than the proactive networks.

2. Weakness

a) TEEN is not suitable for sensing applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached.

D. Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN):

APTEEN [5] is improved from of the TEEN designed to overcome its limitations and goals are to capture both periodic data collections (LEACH) and reacting to time-critical events (TEEN). It combines the best features of both proactive and reactive networks as minimizing their limits to make a new type of network called a hybrid network. APTEEN is based on a query system which allows three types of queries: historical, on-time, and constant which can be used in a hybrid network. In APTEEN the cluster head first broadcasts the following parameters:

a) Attributes -interested physical parameters.
b) Thresholds -hard threshold value and soft threshold value.
c) Schedule -time slot using TDMA.
d) Count time -Maximum time period between two successive reports sent by a node.

1. Strengths:

APTEEN guarantees lower energy dissipation and a larger number of sensors alive. Hence increase network life time.

2. Weakness

a) Overhead and complexity
b) Forming multiple level clusters.

c) Implement threshold-based functions.
d) Dealing with attribute-based naming of query

E. Power Efficient and Adaptive Clustering Hierarchy

In [25] Sangho Yi, proposed a PEACH protocol for WSNs to minimize the energy consumption of each node, and maximize the network lifetime. PEACH [18] also prolong network lifetime of WSNs. It operates on probabilis-tic energy-aware routing protocols [12, 13, 14, 15, 16] such as EAR [12], EAR-DPS [16], and GEAR [13]. Therefore, it has very low power consumption. It supports both routing protocols for WSN i.e. location aware and location un-aware. Location aware protocols are those which provide location information of sensor nodes like PEGASIS [21] and location unaware are those who do not pro-vide location information of sensor nodes like LEACH [23] and HEED [22]. Based on overheard information of each sensor node, this protocol forms adaptive clusters.

In PEACH to achieve the goal of maximizing the lifetime of network with various energy constraints which have been discussed, following things are taken into account while designing the protocol:

Cluster formation overhead:

There are many protocols [19,17, 24, 25] which suffer from overhead of cluster formation as these protocols consumes lots of energy of sensor nodes which are basically battery-limited. Also each non-head node has to transmit the data packet to its Cluster Head even if it is at more distance as compared to BS. This type of reverse forwarding of packet may increase energy consumption of intra-cluster communication. So, cluster formation overhead should be the most important parameter in development of a clustering protocol.

Adaptive multi-level clustering:

As per the condition of WSN, the level of clustering hierarchy must be adaptive in nature. Most of the clustering protocols have fixed level of hierarchical clustering. Fixed level clustering [18] can be affected adversely by distribution of WSNs. So, the clustering proto-cols should have a more adaptive and dynamic hierarchical clustering level.

Cluster formation on PEACH:

Based on the information overheard by each sensor node, this protocol forms adaptive clusters. When a node Ni transmits a packet to node Nj then this protocol defines two sets of nodes:

- **NodeSet(Ni,Nj):** It is a set of all nodes which lies in a circle whose center is node Ni and radius is the distance between nodes Ni and Nj.
- **ClusterSet(Ni,Nj):** It is a set of all nodes which belongs to NodeSet(Ni,Nj) but not in NodeSet(Base station,Nj)

NodeSet(Ni,Nj) consists of nodes which can overhear the transmission of packet from the node Ni to nodeNj and ClusterSet(Ni,Nj)includes CH of all those nodes which are overheard. Node Nj becomes the CH of ClusterSet(Ni,Nj)and it waits for Tdelay to collect multiple packets from other nodes in ClusterSet(Ni,Nj). This set remains active for both before and after Tdelay, selected CH Nj transmits the collected data to next hop in the hierarchy.

In comparison to other protocols it has no overhead on CH selection and it forms an adaptive multi-level clustering. It improves the lifetime and power consumption of WSNs significantly. PEACH protocol supporting location-aware routing (which gives location information of sensor nodes) has lowest power consumption of all the other protocols. It produces clusters which are static and fixed and thus stable. Based on overheard information, it forms clusters without any additional packet transmission of advertisement, announcement, joining and scheduling messages. This protocol design supports its scalability nature. But this algorithm being dynamic produces overlapping clusters which is why we don't prefer this algorithm for our purpose. Node can move from one cluster to another cluster.

1. **Strengths:**
   a) Requires very little or almost no Cluster Formation Overhead.
2. **Weakness:**
   a) Problem of Hot Spots
   b) Residual Energy Not considered here

In Table 1, we present cluster stability, delivery delay, scalability, load balancing and energy efficiency and compare the aforementioned protocols using these terms [26-60].

Table 1: Comparison of Cluster-based Protocols

Protocol Name	Cluster Stability	Delivery Delay	Scalability	Load Balancing	Energy Efficiency
LEACH	Medium	Very Small	Very Low	Medium	Very Poor
TEEN	High	Small	Low	Good	Very High
APTEEN	Very Low	Small	Low	Medium	Medium
HEED	High	Medium	Medium	Medium	Medium
PEACH	Low	Small	Very High	Good	Very High

V. CONCLUSION

In last few years, energy conservation in wireless sensor networks has become one of the most important research areas. The main objective behind the routing protocol design is to keep sensors alive as much as possible, thus prolonging the lifetime of network. For heterogeneous wireless sensor

networks, many energy efficient clustering protocols are proposed which are based on residual energy, density etc. In this paper we have surveyed the past research works which mainly focuses on energy efficient clustering based routing protocols for wireless sensor networks and we have systematically analyzed a few classical WSN clustering routing protocols in deep, and compared these different approaches based some primary metrics. WSN is a broad area so this paper covered only some clustering based routing protocols. Although these routing protocols shows the improvements but still there is possibility of improvements in Wireless sensor networks. Further research would be needed to address issues related to Cluster formation, cluster head communication and data fusion etc.

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