Hierarchical Routing Protocols in WSN: A Review

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Abstract: **The past few years have experienced animmense increase in the use of wireless sensor networks (WSNs) in various applications such as disaster management, border protection and security surveillance. Sensor nodes are expected to be remotely deployed in large numbers, operate autonomously in an unattended environment and they run out of energy very quickly. Hierarchical cluster-based routing protocols are one of the most efficient WSN routing protocols due to their higher energy efficiency and network scalability. In cluster-based routing protocols entire network is divided into varied clusters each with a cluster head (CH) that is used for data aggregation and transmission, and other non CH nodes are used for data sensing. The basic issue with clustering is selection of CH and management of clusters. So, several cluster-based routing protocols have been proposed in the recent past. In this paper, we have conducted a specificsurvey of hierarchical cluster-based routing protocols discussing how they reduce energy consumption and improve network life time.**

Keywords: **Wireless Sensor Networks; Routing Protocols; Single-Hop; Multi-Hop; Clustering; Energy Consumption.**

I. Introduction

Wireless Sensor Network (WSN) consists of large number of independent sensors, communicating with each other through base stations. Sensor nodes are generally attached to microcontroller and are powered by battery making sensor nodes sensitive to energy consumption [1]. The resource constrained nature of WSNs enforces various design and operation issues that can degrade its performance. However, the major issue is inherent limited battery power of sensor nodes which is consumed in transmission and reception of radio signals. Many routing, power management and data dissemination protocols have been proposed for WSNswhich deals with energy consumption as an essential design issue for increasing network lifetime. Out of these protocols, clustering based hierarchical protocols have gained more importance, in increasing the life time of the WSN, because of their approach in cluster head selection and data aggregation.

With respect to widespread WSN's application, a single routing protocol cannot meet all the application requirements [2].Thus, many routing protocols are proposed in the literature.Based on the underlying network, WSN protocols are classified as [3]:

- Flat Routing Protocols:Each node plays the same role in the network nodes collaborate to perform the sensingtask.Eg, AODV, DSDV, Directed Diffusion etc.
- Hierarchical Routing Protocols: In this, nodes are designated specific tasks based on their energy levels.High energy nodes are used for processing and sending the information whereas small energy nodes are used for sensing in the proximity of the target. The creation of clusters and cluster heads in hierarchical protocols can contribute significantly to network scalability, lifetime and energy efficiency. In this type of routing is an effective way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink node. Eg, LEACH, HEED, PEGASSIS etc.
- Location-based Protocols: Sensor nodes are addressed by means of their positions. The distance between sensor nodes and neighboring's nodes can be estimated on the basis of incoming signal strengths. Relative coordinates of other and neighboring nodes can be obtained by exchanging such information between sensor & neighbors or by communicating with a satellite using GPS. Eg. GEAR, GAF etc.

II. Hierarchical Routing Protocols in WSN

a) LEACH (Low Energy Adaptive Clustering Hierarchy): LEACH is TDMA based MAC protocol & the earliest distributed hierarchical based clustering protocol proposed for WSN in which sensor nodes self-organize themselves into clusters to increase network lifespan [4]. The routing process of LEACH involves several rounds, where each round consists of: Setup phase and Steady state phase. In the first round Set up phase initiates with the formation of clusters and one of the nodes in a cluster is selected as cluster head (CH) with remaining nodes acting as member nodes of this cluster. CHs are responsible for collecting the data from all member nodes of a cluster, aggregating the data packets received and routing data packets to base station (BS) after compression to reduce energy dissipation. If the selected node remains CH permanently, its energy will be dissipated quickly so the process of cluster selection repeats for every round and CHs are selected in randomized fashion to save the battery power of CH.

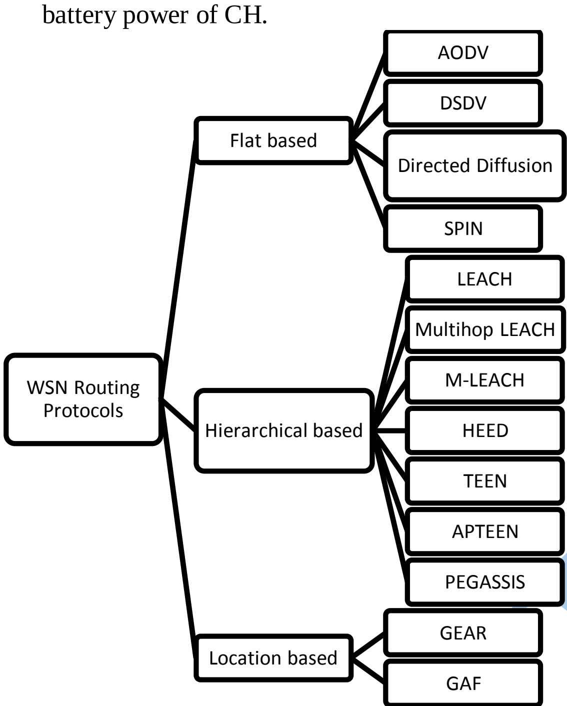

Figure 1. Classification of routing protocols

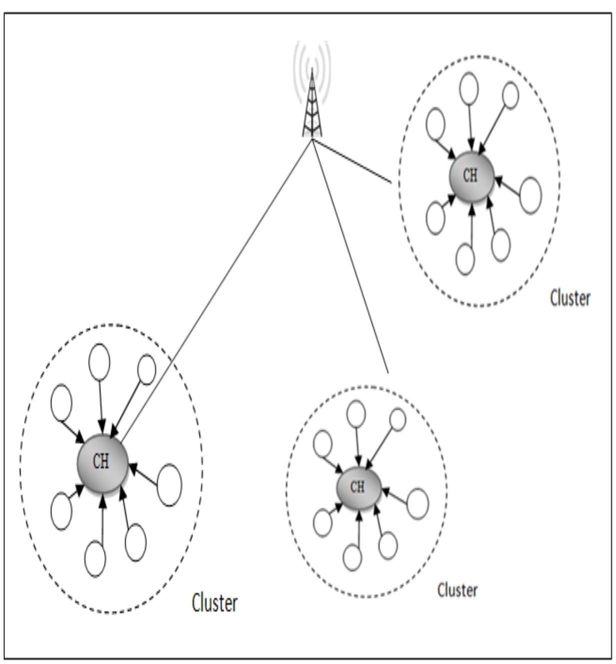

Figure 2. Clustering in LEACH

Some sensor nodes independently elect themselves as CHs without any negotiation to other nodes. CHs elect themselves on basis suggested percentage P and their previous record as a CH. Every node which is not selected as CH previously in 1/p rounds generates some random number between 0 and 1 and the node announces itself in CH if this number is less than threshold value. The threshold value of a node is zero for the node that has already been CH in the recent past so that this node can't be selected as CH again. The nodes that have not been selected as CH, they have threshold T (n) possibility of being selected as CH.

$$\text{Threshold (n)} = \begin{cases} \frac{P}{1-P\left(r \bmod \left(\frac{1}{p}\right)\right)} \forall n \in G \\ 0 \qquad if n \notin G \end{cases}$$

Wherep is desired probability of CH election, r is the current round in, and G is the set of nodes in that haven't been selected as CH in last 1/p rounds. So each node elected as CH can be CH again after 1/p rounds. In LEACH, every node will serve as CH equally and energy dissipation will be uniform throughout the network.

In steady state phase, nodes within a cluster communicate with their respective CHs during allocated time slots and sleeps rest of the time. This sleeping minimizes energy dissipation and extends battery lifetime of all member nodes. As soon as the data from all nodes of a cluster is received by CH, it will be aggregated, compressed and transmitted to BS. CHs broadcast their status usingCSMA/CA protocol and create TDMA schedule for other member nodes in the cluster. Non cluster head nodes select their CHs by comparing Received Signal StrengthIndication (RSSI) of multiple CHs, from where nodes receive advertisements messages.

b) Multi-hop LEACH

It is an extension of LEACH for enhancing energy efficiency of WSN [5, 6]. LEACH is unsuitable for large networks when network diameter increases beyond limit because distance between CH and BS becomes large and the transmission energy cost of CHs becomes unaffordable. Multi-hop LEACH basically addresses this issue. The setup phase is similar to LEACH in which some nodes elect themselves as CHs in other nodes get associated with elected CHs to complete cluster formation. Steady phase is slightly different from LEACH because in multi-hop LEACH, CHs collect data packets from all the member nodes of their respective cluster and transmit data packets either directly or through other CHs to BS after aggregation. Multi- Hop LEACH allowed both inter-cluster communication and intra-cluster communication.Multi-Hop LEACH routing is shown in Figure 3.

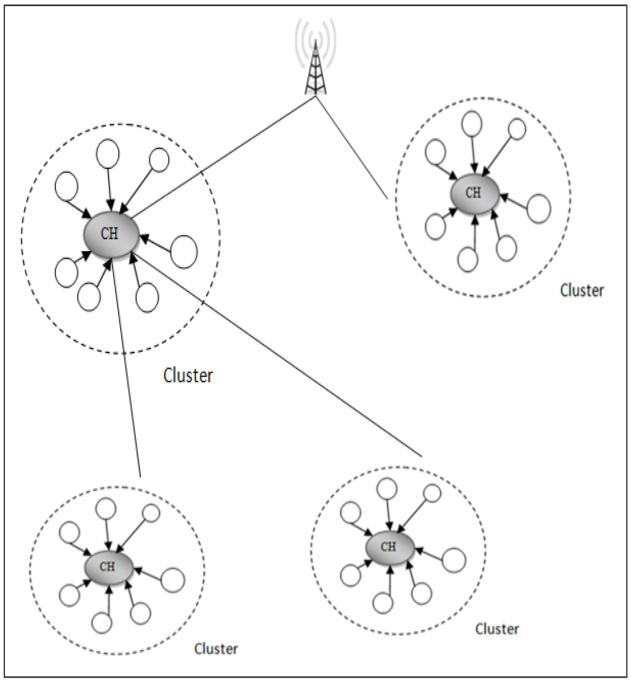

Figure 3. Multi-Hop LEACH

The whole network is divided into multiple clusters with each cluster having one CH. CH communicates with all the nodes in the cluster and receives data from all non CH nodes at single-hop, aggregates data and transmits directly to BS or through intermediate CHs. In Multi-hop LEACH inter-cluster communication, CH uses intermediate CHs to communicate to BS when distance between CH and BS is larger. CH is selected using randomized rotation as in LEACH. Multi-Hop LEACH selects best possible path with minimum hop count and energy dissipation. An intermediate CH is selected in a way to keep overall distance towards BS minimum as distance is directly proportional to energy dissipation.

c) **Mobile LEACH (M-LEACH)**

LEACH protocol does not support mobility and assumesall nodes to be fixed and homogeneous with respect to their energy. In everyround,uneven nodes may beattached tomultiple CH. It may also be possible that CHs with large number of member nodes will drain their energy quickly as comparedto CHs linked with smaller number of member nodes. M-LEACH was proposed to mitigate these issuesand to conform to more realistic situations [7].

M-LEACH supports mobility of nodes during the setup and steady state phase with some assumptions.Initially sensor & CH nodes arebv equivalent in termsof antenna gain and all nodes have their positions information through Global Positioning System (GPS) and BS is fixed. Distributedsetup phase of LEACH is modified inM-LEACH thatselectsmost suitable CHs. MLEACH also considers remaining energy of the nodes while selecting CHs. In M-LEACH, CHs are select on the basis of attenuation model and mobility speed [8]. Nodes with minimum mobility and lowest attenuation power are selected as CHs. Theselected CHs further broadcast their status information to all nodes within their transmission range.Nodes compute their willingness for sending data from multiple CHs and select the CH with higher unused energy.

In steady phase, if non CH nodes move away from CH or if CH moves away from its member nodes than another CH will become more suitable for that cluster. M-LEACH provides handover process for nodes to switch on to new CH to deal with this node movement. When nodes decide for handoff, they DISJOIN message to current CH and JOIN-REQ to new CH. After handoff, CHs re-schedule the transmission pattern for member nodes.

d) **Hybrid, Energy-Efficient Design Clustering (HEED):**HEED [9, 10] extends the basic mechanism of LEACH by including unused energy and node degree or density as a metric for cluster head selection to ensurebetter power balancing. It operates in multi-hop networks, using an adjustive transmission power in the inter-clustering communication. HEED was primarily proposed with four objectives:

- Increased network lifetime by distributing energy consumption across the network
- Terminate the clustering process within a continuous number of iterations
- Minimize control overhead
- Produce well-distributed CHs and compact clusters.

The process of clustering in HEED improves network lifetime as compared to LEACH because LEACH randomly selects CHs and cluster size, that results in faster death of some nodes. But in HEED, CHs selected are well issues across the network and the overall transmission cost is minimized. This methodisonly suitable for increasing the network lifetime than the entire needs of WSN because CH selection is based on combination of two parameters which can impose constraints on the overall system.The foremost parameter is residual energy of each sensor node which is used in calculating probability of becoming a CH and the second parameter is the intra-cluster transmission cost which is a function of cluster weight or node degree (i.e. number of neighbors). The first parameter choose an initial set of CHs probabilistically and the second parameter is used for breaking ties if arises.The clustering process requires several rounds and every round is long enough to receive messages from any neighboring node within the cluster [29]. Similar to LEACH, an initial percentage of CHs in the network C_{prob}, is predefinedto limit the initial CH announcements and has no effect on the final cluster formation. In HEED, each sensor node sets the probability $CH_{prob}$of becoming a CH as follows:

$$CH_{prob} = C_{prob} \cdot \frac{E_{residual}}{E_{max}}$$

where $E_{residual}$ is the current residual energy of a sensor node and E_{max} is the maximum energy when its battery is fully charged. The CH_{prob} value must be greater than a minimum threshold, i.e, p_{min}. A CH is either a tentative CH, if its CHprob is <1, or a final CH, if its CH_{prob} has reached 1. During each round of HEED, every sensor node that never heard from a CH elects itself to become a CH with probability CH_{prob}. The newly elected CHs are added to the current set of CHs. If a sensor node is selected to become a CH, it broadcasts an announcement message as a tentative CH or a final CH, whatever the case may be and sensor nodeslistening to the CH list selects the CH with the lowest cost from this set of CHs.

Every node then doubles its CH_{prob} and goes to the next step. If a node completes the HEED execution without electing itself to become a CH or joining a cluster, it announces itself as a final CH. A tentative CH node can become a regular node at a later iteration if it hears from a lower cost CH. Here, a node can be selected as a CH at consecutive clustering intervals if it has higher residual energy with lower cost.

e) **Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN):** TEEN [11, 12] is another hierarchical clustering protocol best suited for reactive networks. TEEN also groups sensor nodes into clusters and each cluster is led by a CH. The sensor nodes within a cluster report their sensed data to their CH which in turn sends aggregated data to higher level CH until the data reaches the sink or BS. Thus, the sensor network architecture in TEEN is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the BS is reached as shown in Figure 4 below.

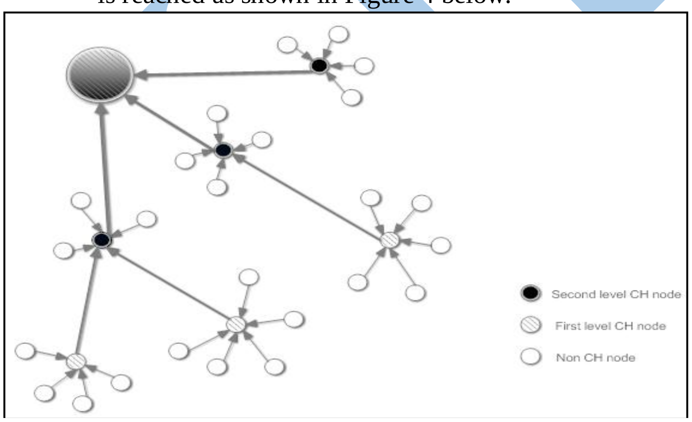

Figure 4. Hierarchical Clustering in TEEN and APTEEN

TEEN enables CHs to impose a constraint on when the sensor nodes can report their sensed data to CH. After the clusters are formed, the CH broadcasts two thresholds to the nodes: hard threshold (HT) and soft threshold (ST). Hard threshold is the minimum possible value of an attribute, beyond which a sensor should turn its transmitter ON to report its sensed data to its CH. The hard threshold allows the nodes to transmit only when the sensed attribute has reached a certain level, thus reducing the number of transmissions significantly. Once a node senses a value known as sensed value (SV) at or beyond the hard threshold, it transmits data only when the value of that attribute changes by an amount equal to or greater than the soft threshold, which indicates a small change in the value of the sensed attribute and triggers a sensor to turn ON its transmitter and send its sensed data to the CH. Soft threshold will further reduce the number of transmissions for sensed data if there is little or no change in the value of sensed attribute. Thus, the sensor nodes will send only sensed data to the end user based on the hard threshold value and the change with respect to the previously reported data, thus yielding more energy savings. Hard and soft threshold values should be chosen very carefully to keep the sensors responsive by reporting sensed data to the sink.

An application of TEEN is for time critical sensing applications. The energy consumption is less than the proactive networks as transmission consumes more energy than data sensing. The soft threshold can be varied by the user during cluster change time by broadcasting fresh parameters. TEEN is unsuitable for sensing applications that requires periodic reports because the user might not get any data if the threshold values are not met.

f) **Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN):** APTEEN [13] is an enhancement over TEEN to overcome its shortcomings and aims at both capturing periodic data reports as in LEACH and reacting to time-critical events like TEEN. Thus, APTEEN is considered as hybrid clustering-based routing protocol that allows the sensor nodes to send their sensed data periodically and react to any sudden change in the value of the sensed attribute by reporting the corresponding values to their CHs. The architecture of APTEEN is same as in TEEN, which uses the concept hierarchical clustering for energy efficient routing between sensor nodes and the sink. After cluster formation and selection of CH, CH of respective cluster broadcasts the attributes, the hard and soft threshold values, TDMA transmission schedule to all the member nodes, and a maximum time interval between two successive reports sent by nodes. CHis also responsible for data aggregation to save energy. APTEEN allows three different queries: historical query that analyzes past data values, one-time query that takes a snapshot of network view and persistent queries for monitoring an event for certain duration of time.

APTEEN ensures low energy dissipation and a larger number of live nodes [47]. The performance of APTEEN lies between LEACH and TEEN in terms of energy dissipation and network lifetime. LEACH allows sensor nodes to transmit their sensed data continuously to the sink whereas in APTEEN sensor nodes are allowed to transmit their sensed data based on the hard and soft threshold values. The major drawback is the overhead and complexity involved in cluster formationat multiple levels, implementing thresholdbased functionality and dealing with attribute-based naming of queries.

g) **Power-Efficient Gathering in Sensor Information Systems(PEGASIS):** PEGASIS [14] is an improvement of the LEACH protocol, in which instead of forming multiple clusters, chains of sensor nodes are formed so that each node transmits and receives from its neighbor only and one of the node known as head of the chain is selected from that chain to transmit to the base station (sink). The objectives of PEGASIS routing protocol are to extend the lifetime of each node by using collaborative techniques and local coordination and communication with their closest neighbors so that the bandwidth consumed in communication is reduced. The data is gathered and moves from node to node, aggregated and eventually sent to the base station. The chain construction is either performed in a greedy way by nodes or by BS which broadcasts to sensor nodes.
In data fusion phase, a sensor node transmits data to its local neighbors instead of sending data directly to its CH as in the above protocols. This protocol assumes that all the sensors have global knowledge about the network, particularly, the positions of the sensors. When a sensor nodebecomes dead due to low battery power, the chain is constructed again using the same greedy approach by bypassing the deadnode. A random node is chosen from the chain in each round that will communicate with BS and transmit aggregated data to BS, reducing energy required for transmission per round as energy consumption is uniformly distributed over all nodes. Each node uses the signal strength to locate its closest neighbor,measures the distance to all neighboring nodes and then adjusts the signal strength so that only one node can be heard.

Table 1. Comparison of the hierarchical routingprotocol

III. CONCLUSION

In this paper, WSN routing protocols are discussed on the basis of network structure. The biggest challenge in design of WSN protocols is scarce energy resources of sensor nodes and these protocols tends to extend the battery lifetime by reducing the energy consumption of the sensor nodes. Hierarchical based protocols have special advantage of scalability and efficient communication. Hierarchical routing maintains the energy consumption of sensor nodes and performs data aggregation which helps in decreasing the number of transmitted messages to base station. The various protocols discussed have pros and cons and each is suitable for particular kind of application. QoS requirements such as delay, fault tolerance, and network lifetime play an important role in designing an efficient clustering algorithm. The factors affecting cluster formation and CHs communication are open future research issues that still need to be resolved.

WSN Protocol	Node mobility	Scalability	Distributed	CH Selection Criteria	Resource awareness	Energy efficiency	Network Topology	Merits	Demerits
LEACH	Fixed BS	Limited	No	Random to minimize energy dissipation	Good	Low	Single hop	Avoid battery depletion and balance the energy consumption among the nodes.	Energy wastage duringCH selectionphase. Consume a large amount of energy if the CH is located far away from sink.Noguarantee of good CHs distribution.
Multi-hop LEACH	Fixed BS	Limited	Yes	Random to keep hop count and energy dissipation minimum	Very good	Very high	Multi hop	Suitable for large-size networks.	Suffers from hotspots. Limited scalability
M-LEACH	Mobile BS and nodes	Good	Yes	Residual energy and node mobility	Very good	Very high	Single hop	Highly scalable. Provides handover mechanism	Relatively high overhead.
HEED	Stationary	Limited	Yes	Residual energy and node degree	Good	High	Multi hop	Balance power among nodes.Reduce control overhead. Fairly CHs distribution	Limited scalability. Causes a delay
TEEN	Fixed BS	Good	Yes	Random	Good	Very High	Single hop	Suitable for reactive networks.	High overhead and doesn't suits well for proactive networks.
APTEEN	Fixed BS	Good	Yes	Random	Good	High	Single hop	Suitable for both proactive and reactive networks	Overhead and complexity involved in cluster formation at multiple levels, implementing threshold based functionality.
PEGASIS	Fixed BS	Very good	Yes	Random	Very good	Very high	Multi hop	Less clustering overhead and equal energy distribution	Requires dynamic topology adjustment. Significant overhead especially for highly utilized networks

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