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SURVEY ARTICLE

Various Hierarchical Routing Protocols in Wireless Sensor Network: A Survey

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Abstract— ***In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing. Numbers of routing, power management, and data dissemination protocols have been specifically designed for WSNs where energy awareness is an essential design issue. The focus has been given to the hierarchical routing protocols which might differ depending on the application and network architecture. In this paper we discuss some of the hierarchical routing protocols that give an overview of different hierarchical routing strategies which is used in WSN and their performance is compared based on metrics such as localization, data aggregation, power usage.***

Key Terms: - hierarchical routing protocol; routing protocol; clustering; lifetime; wireless sensor network

I. INTRODUCTION

Hundreds and thousands of sensors are deployed in wireless sensor network according to the requirement of network application. Wireless sensor network (WSN) is one of the evolving technologies. Sensor nodes are able to monitor physical environment, compute and transmit this information to core network. These sensors can communicate to each other and also to some external Base station [1].Wireless sensor network are used for both military and civil applications [2].A wide-range of applications offered by WSN, some of these are environmental monitoring, industrial sensing, infrastructure protection, battlefield awareness and temperature sensing. Generally a Wireless Sensor Network (WSN) is composed of a large number of wireless sensors with low processing power and energy consumption for monitoring a certain environment. The large number of nodes and their random placement in space offers great redundancy in data transmission. Consequently WSN are generally adaptive networks that use data aggregation and hierarchy to reduce energy consumption.

Routing is main challenge faced by wireless sensor network. Routing is complex in WSN due to dynamic nature, limited battery life, computational overhead, no conventional addressing scheme, self-organization and limited transmission range of sensor nodes [3]. As sensor has limited battery and this battery cannot be replaced due to area of deployment, so the network lifetime depends upon sensors battery capacity. A Careful management of resources is needed to increase the lifetime of the wireless sensor network. Quality of routing protocols depends upon the amount of data (actual data signal) successfully received by Base station from sensors nodes deployed in the network region. The protocol of WSN can be classified two kinds of protocols, planar routing protocol and hierarchical routing protocol. Hierarchical routing based clustering not only advance network scalability and reduces data delay, but also it supports data aggregation in varying degrees to prolong the network lifetime [4].

Generally, routing protocols are divided in to 3 main groups:

1. Flat
2. Hierarchical
3. Location based

In this paper, we will discuss Hierarchical routing protocol. Hierarchical routing protocols have proved to have considerable savings in total energy consumption of the WSN. In hierarchical routing protocols whole network is divided into multiple clusters. Clusters are created and a head node is assigned to each cluster. The head nodes are the leaders of their groups having responsibilities like collection and aggregation the data from their respective clusters and transmitting the aggregated data to the BS. This data aggregation in the head nodes greatly reduces energy consumption in the network by minimizing the total data messages to be sent to BS.

The less the energy consumption, the more the network life time. The main idea of developing cluster-based routing protocols is to reduce the network traffic toward the sink. This method of clustering may introduce overhead due to the cluster configuration and maintenance, but it has been demonstrated that cluster-based protocols exhibit better energy consumption and performance when compared to flat network topologies for large-scale WSNs. Description of some hierarchical routing protocols is discussed in next subsections.

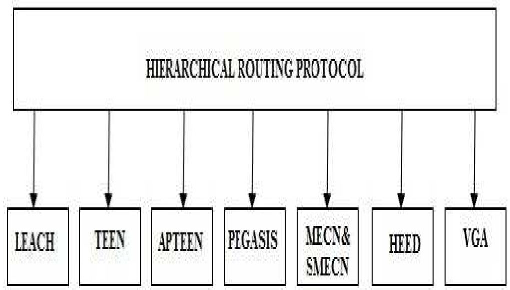

Fig1**.** Hierarchical Routing Protocol

II. HIERARCHICAL ROUTING PROTOCOL

A. LEACH

Heinzelman, et. al. [5] introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). Low Energy Adaptive Clustering Hierarchy is one of the first hierarchical routing protocols for sensor network. The conventional clustering technique used in wireless sensor networks does not improve network lifetime since this scheme assumes the cluster heads to be fixed, and thus requires them to be high-energy nodes. Low-Energy Adaptive Clustering Hierarchy (LEACH) presented in [6] provides a hierarchical protocol that makes the use of local coordination among the nodes to enable scalability and robustness for sensor networks. So, LEACH is an energy conserving communication protocol where all the nodes in the network are uniform and energy constrained. An end user can access the remotely monitored operation, where large numbers of nodes are involved. The nodes organize themselves into local clusters, with one node acting as the randomly selected local cluster head. If the allocated cluster heads are always fixed, then they would die quickly, ending the useful lifetime of all nodes belonging to those clusters. LEACH includes random alternation of the high-energy cluster head nodes to enable the sensors to uniformly sustain the power. Sensors nominate themselves to be local cluster heads at any given time with some probability. These cluster head nodes relay their status to the other sensors in the network. Each sensor node resolves which cluster to follow by choosing the cluster head that requires the minimum communication energy. This allows the transceiver of each unassigned node to be turned off at all times except during it’s transmit time, thus minimizing the energy dissipated in each sensor. The LEACH operates based upon rounds. Each round includes two stages:

1. Cluster-constructing (Set-up phase)
2. Working steadily (Steady-state phase)

Set-Up Phase: Cluster is constructed by CH election. Each node decides independent of other nodes if it will become a CH or not. This decision takes into account when the node served as a CH for the last time (the node that hasn't been a CH for long time is more likely to elect itself than nodes that have been a CH recently). The duration of the steady state phase is longer than the duration of the setup phase in order to minimize overhead. During the setup phase, a predetermined fraction of nodes, p, elect themselves as CHs as follows.

A sensor node chooses a random number, r, between 0 and 1. If this random number is less than a threshold value, T(n), the node becomes a cluster-head for the current round. equation that incorporates the desired percentage to become a cluster-head, the current round, and the set of nodes that have not been selected as a cluster-head in the last (1/P) rounds, denoted by G. It is given by:

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

Where G is the set of nodes, which are involved in the CH election. Each elected CH broadcast an advertisement message to the rest of the nodes in the network that they are the new cluster-heads. All the non-cluster head nodes, after receiving this advertisement, decide on the cluster to which they want to belong to. This decision is based on the signal strength of the advertisement. The non-cluster-head nodes inform the appropriate cluster-heads that they will be a member of the cluster. After receiving all the messages from the nodes that would like to be included in the cluster and based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule and assigns each node a time slot when it can transmit. This schedule is broadcast to all the nodes in the cluster.

The setup phase [11] is further divided into

- Advertisement Phase
- Cluster set-up phase

In the advertisement phase, the randomly generated CHs advertise their election as clusters to its neighborhood sensor nodes. This is followed by the Cluster set-up phase where the sensor nodes which received the advertisement can join the CH with higher signal strength. Then the steady-state phase begins.

Steady-State Phase: The Data transmission from the source sensor node to the destination sink happens in the Steady state phase where the CH is maintained. Like set-up phase, the Steady-state phase [7] can be further classified into the following:

- Schedule Creation
- Data transmission

The Schedule is created by breaking the Steady-state operation into frames, and the timeslots are allocated for each of the sensor nodes. The nodes send their data to their CH during their allocated TDMA slot [7]. When all the data are received, the CH aggregates them and sends the aggregated data to the Sink Node. Figure 1. Describes the operation of LEACH during different phases-

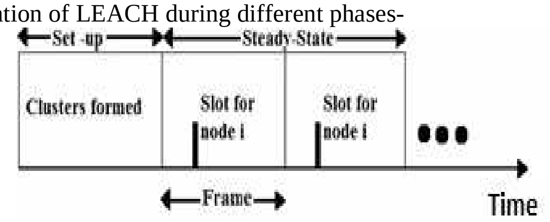

Fig2. Time Line operation of LEACH [8]

B.TEEN

Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [9], is a hybrid of hierarchical clustering and data-centric protocols designed for time-critical applications. i.e. it is designed to be responsive to abrupt variations in the sensed physical attributes such as temperature, pressure etc. In TEEN, physical phenomenon is sensed constantly, but the actual data transmission is done sparingly. Nodes that are closer together form clusters and this process continues throughout the network until the sink node is reached. Basically, TEEN protocol has been developed for reactive networks so that to respond for the sudden changes in the sensed attributes. This makes it appropriate for the time critical application. However, TEEN is not suitable for applications where periodic reports are needed, because if the thresholds are not received, the nodes will never communicate with each other, and the user will not get any data at all from the network. The algorithm first goes through cluster formation. The CHs then broadcast two thresholds to the nodes in their clusters. Those are hard and soft thresholds for the sensed attribute.

Hard Threshold (HT): This is a threshold value for the sensed attribute. It is the absolute value of the attribute beyond which, the node sensing this value must switch on its transmitter and report to its cluster head.The hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest.

Soft Threshold (ST): This is a small change in the value of the sensed attribute which triggers the node to switch on its transmitter and transmit. It stimulates the node to switch on its transmitter and report the sensed data. A node will report data only when the sensed value is beyond the HT or the change in the value is greater than the ST. However, TEEN cannot be applied for sensor networks where periodic sensor readings should be delivered to the Sink, since the values of the attributes may not reach the threshold at all. Moreover, we have some wasted time-slots in TEEN protocol and there is always a possibility that the sink may not be able to distinguish dead nodes from alive ones. Another limitation of the protocol is that the message propagation is accomplished by CHs only. If CHs are not in each other's transmission radius, the messages will be lost.

C. APTEEN

APTEEN (Adaptive Threshold sensitive Energy Efficient sensor Network protocol) [10] is an advancement to TEEN. It is intended to acquire periodic data collections and is more receptive to time-critical events depending on the type of the application. It works similar to that of TEEN. In this routing protocol, cluster head broadcasts transmission schedule in addition to thresholds values as in TEEN. In this way, it becomes feasible to capture data on periodic manner and if a node does not send data for a time period equal to the count time. In APTEEN, the count time is the maximum time period between two successive reports sent by the sensor node. If the sensor node does not send data beyond the count time, TDMA schedule is used and each node in the cluster is assigned a transmission slot. The performance evaluation of TEEN and APTEEN shows that both of them outperform LEACH.

D. PEGASIS

In [11], an enhancement over LEACH protocol was proposed. The protocol, called Power-Efficient Gathering in Sensor Information Systems (PEGASIS), is a near optimal chain-based protocol. This algorithm decreases the energy consumption by creation of a chain structure comprised of all nodes and continually data aggregation across the chain. The algorithm presents the idea that if nodes form a chain from source to sink, only one node in any given transmission time-frame will be transmitting to the base station. Data-fusion occurs at every node in the sensor network allowing for all relevant information to permeate across the network. PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS instead of using multiple nodes. In order to increase network life time, nodes need only to communicate with their closest neighbors and they take turns in communicating with the BS. When the round of all nodes communicating with the base-station ends, a new round will start and so on. This reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes. PEGASIS has two main objectives:

- First, increase the lifetime of each node by using collaborative techniques and as a result the network lifetime will be increased.
- Second, allow only local coordination between nodes that are close together so that the bandwidth consumed in communication is reduced.

E. MECN and SMECN

Minimum Energy Communication Network (MECN): By using low power GPS devices, sensor nodes in MECN can setup and maintain a minimum energy network [12]. The main idea of MECN is to find the sub-network with the smallest number of nodes that requires the least transmission power between any two particular nodes (shortest path).MECN assumes a master-node as the information sink and develops a minimum power topology for each node. MECN identifies a relay region for each node, which is consisted of nodes in a surrounding area where transmitting through those nodes is more energy-efficient than direct transmission. A sub-network build in MECN is based on having less number of nodes which can consume less power for transmission between any two specific nodes. In this way, global minimum power paths are found without considering all the nodes in the network. Optimal links are calculated based on the position coordinates updated by using GPS. Moreover it can dynamically adapt to elimination of nodes or the deployment of new sensors since it is capable of self-reconfiguring.

The Small Minimum Energy Communication Network (SMECN) [13] is an extension of MECN. The major drawback with MECN is that it assumes every node can transmit to every other node, which is not always possible. One advantage of SMECN is that it considers obstacles between pairs of nodes. Geographic Adaptive Fidelity (GAF) [14] is an energy-aware location-based routing algorithm primarily designed for adhoc networks that can also be applied to sensors networks. GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. Finally, Geographic and Energy Aware Routing [15] uses energy-awareness and geographically informed neighbor selection heuristics to route a packet toward the destination region.

F. HEED

HEED (Homes Energy Efficiency Database) [16] extends the basic scheme of LEACH by using residual energy and node degree or density as a metric for cluster selection to achieve power balancing. It operates in multi-hop networks, using an adaptive transmission power in the inter-clustering communication.

HEED was proposed with four primary goals namely-

(i) Prolonging network lifetime by distributing energy consumption.
(ii) Terminating the clustering process within a constant number of iterations.
(iii) Minimizing control overhead.
(iv) Producing well-distributed CHs and compact clusters.

In HEED, the proposed algorithm periodically selects CHs according to a combination of two clustering parameters. The primary parameter is their residual energy of each sensor node (used in calculating probability of becoming a CH) and the secondary parameter is the intra-cluster communication cost as a function of cluster density or node degree (i.e. number of neighbors). The primary parameter is used to probabilistically select an initial set of CHs while the secondary parameter is used for breaking ties.

In HEED, the clustering process at each sensor node requires several rounds. Every round is long enough to receive messages from any neighbor within the cluster range[17]. As in LEACH, an initial percentage of CHs in the network C_{prob}, is predefined. The parameter C_{prob} is only used to limit the initial CH announcements and has no direct impact on the final cluster structure. 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 estimated current residual energy in this sensor node and E_{max} is the maximum energy corresponding to a fully charged battery, which is typically identical for homogeneous sensor nodes. The CH_{prob} value must be greater than a minimum threshold p_{min}. A CH is either atentative CH, if its CH_{prob} 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 selected 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. A sensor node hearing 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.

G.VGA

Virtual Grid Architecture routing (VGA) it is a GPS-free technique to split the network topology into logically symmetrical, side by side, equal and overlapping frames (grids) [18]. And the transmission is occurred grid by grid [19]. VGA provides the capability to aggregate the data and in-network processing to increase the life span of the network. Data aggregation is done in two steps i.e. first at local level (in grid) and then globally. The nodes that are responsible to aggregate data locally are 'local heads' (grid heads) and the nodes 'global heads' have to aggregate data received from local heads [19]. After the formation of logical grids, election is started in each grid to decide for the local head of the grid based on node the energy and how many times it has been selected as local head. And then the global heads are also selected randomly from the selected local heads. Several local heads may connect to the global head [18]. The local heads are allowed to communicate vertically and horizontally only. Each node within the grid that has the required data will send its data to the local head. Then the local head will aggregate the data and send it to its associated global head that will also aggregate the data again and send it to the BS via other global heads. If a local head or global head dies, a new local/global head is selected after the election [19].

III. COMPARISON OF VARIOUS HIERARCHICAL ROUTING PROTOCOLS

Protocols	BS is Fixed or not	Power usage	Data Aggregation	Localization	Negotiation Based	Scalability	Multipath	State Complexity
Leach	Yes	Maximum	Yes	Yes	No	Good	No	CHs
Teen & Apteen	Yes	Maximum	Yes	Yes	No	Good	No	CHs
Pegasis	Yes	Maximum	No	Yes	No	Good	No	Low
MECN & SMECN	No	Maximum	No	No	No	Low	No	Low
HEED	FixedBS	N/A	Yes	Yes	No	Good	Yes	CHs
VGA	No	N/A	Yes	Yes	Yes	Good	Yes	CHs

Table1. Comparison of routing protocols

IV. CONCLUSION

In this paper, we discussed various hierarchical routing protocols like LEACH, TEEN, APTEEN, PEGASIS, HEED, VGA, MECN and SMECN for wireless sensor network. The main concern of this survey is to examine the mobility, data aggregation, power usage, multipath, scalability and compare the performance of all the hierarchical protocols.

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